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AVO Modelling Considering Various Caprock and Reservoir Scenarios for Potential CO2 Storage in Smeaheie Area, Northern North Sea

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Summary

Unlike a hydrocarbon accumulation where we are sure of a working reservoir and the caprock integrity, the CO2 storage has many unknowns before the gas is injected and placed there. To reduce this risk it is imperative to model all the possible scenarios before taking a major decision for CO2 storage. To evaluate subsurface reservoirs and caprocks for CO2 sequestration, the CO2 plume movement while injection and subsequent changes in the elastic properties at the reservoir-caprock interface are important. The AVO method might provide us with a tool to detect the position and level of saturation of CO2 in a reservoir while and after injection. The upper Jurassic Sognefjord Formation is a potential CO2 storage formation overlain by the Heather and Draupne Formations considered to be the cap rocks in the Smeaheie area within the northern North Sea. In this study we considered two different reservoir-caprock cases with five different saturation, pressure and temperature scenarios for each case to check the sensitivity of the AVO method in this area. These findings will help understanding the change in elastic properties at the reservoir-caprock interface as a function of CO2 saturation, facilitating detection of its migration and possible phase changes.

Introduction

This study deals with the rock physics evaluation and AVO modelling of the Draupne and Heather Formations (Upper Jurassic) shale caprocks above Sognefjord Formation (Upper Jurassic, Oxfordian to Kimmeridgian) sandstone that is a potential CO_2 reservoir in the Smeaheie area within the northern North Sea. Norwegian authorities have been evaluating for viability of large-scale (Gt storage potential) CO_2 storage sites in various parts of the Norwegian Continental Shelf. The Smeaheia area is one of a potential CO_2 storage site located in the Stord Basin, which is bounded by a fault array separating the Troll Field in the west and the Basement Complex in the east (Figure 1). The Troll Field is situated approximately 80 km WNW of the city of Bergen.

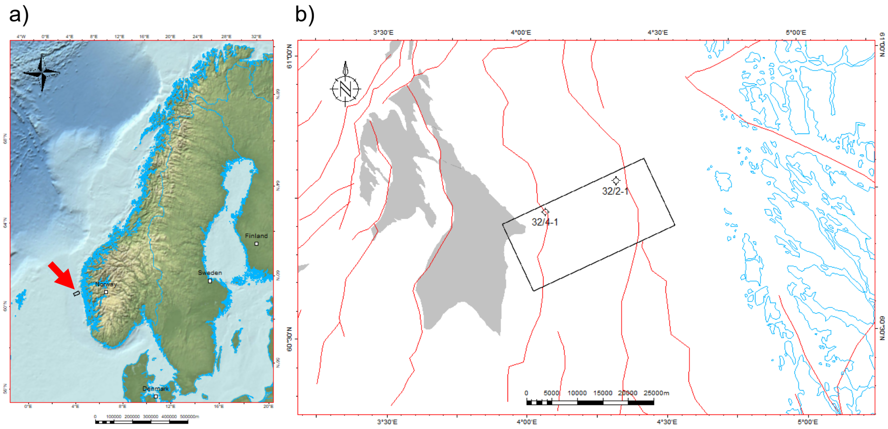

Figure 1 *The study area is shown as black rectangle, highlighted by a red arrow (a). The Smeaheia area is located in the Stord Basin, which is bounded by a fault array separating the Troll Field (shaded grey) in the west and the Basement Complex in the east. Two dry wells drilled in the area have data in our access (b).*

The Sognefjord Formation consisting of coastal-shallow marine sands overlain by the Heather and Draupne Formations. The Heather Formation consists of mainly of silty claystone with thin streaks of limestone. On the Horda Platform where the Heather Formation interfingers with sandstones of the Krossfjord, Fensfjord and Sognefjord Formations, it becomes in places highly micaceous and may grade into a sandy siltstone (NPD, 2018). The Draupne formation consists of dark grey-brown to black, usually non-calcareous, carbonaceous, occasionally fissile claystone. It is characterized by very high Gamma Ray radioactivity (often above 100 API units), because of organic carbon content. The Draupne Formation was deposited in a marine environment with restricted bottom circulation and often with anaerobic conditions (NPD, 2018). Based on the two wells (32/2-1 and 32/4-1) in the area the Heather Formation thickness is around 20m, whereas Draupne Formation thickness ranges from about 60 to more than 100m.

This study attempts to investigate and model scenarios to help predicting various risks involved while injecting and storing the CO_2. The geologic evaluation of an area for CO_2 storage warrants reservoir as well as the seal and overburden characterization. In case of a hydrocarbon trap the oil/gas accumulation is itself a proof of the cap-rock and the overburden integrity, however in regard of CO_2 storage a careful investigation is required to avoid any CO_2 leakage risk.

Mehtod and/or Theory

Two wells 32/4-1 and 32/2-1, and a 3D volume GN1101 covering the area were available for the study. Synthetic S- wave velocity logs were generated using Greenberg and Castagna (1992) model, and a preliminary rock physics analysis was carried out using the data from the two available wells to investigate the range of depth, temperature and their possible influence on the elastic properties (Figure 2). Well 32/4-1 was selected to carry out an AVO modelling. The Gamma Ray log in addition to the elastic property logs (i.e. Vp, Vs and Density) were blocked using Backus averaging. A window of 25m was found appropriate for blocking to represent the main interfaces in correlation with seismic. The P- wave log that was already corrected using the checkshots was correlated again with the seismic to get the depth to time relationship. The fluid parameters for fluid replacement modelling were calculated using FLAG 2014 method. Two cases were considered for AVO modelling; A) Interface between the Sognefjord reservoir and the Heather mudstones considering latter as a caprock and B) Interface between the Heather and the Draupne Formations assuming the Heather being more silty resulting in CO_2 accumulation. Following scenarios were run for each case:

1. In-situ brine saturated reservoir, with pressure 12 MPa & temperature 38°C.
2. Reservoir with 80% supercritical CO_2, homogenous saturation (Reuss average), with pressure 12 MPa & temperature 38°C.
3. Reservoir with 80% supercritical CO_2, patchy saturation (Brie et al. 1995), with pressure 12 MPa & temperature 38°C.
4. Reservoir with 80% gaseous CO_2, homogenous saturation (Reuss average), pressure depletion to 5MPa and temperature reduced to 30°C.
5. Reservoir with 80% gaseous CO_2, patchy saturation (Brie et al. 1995), pressure depletion to 5MPa and temperature reduced to 30°C.

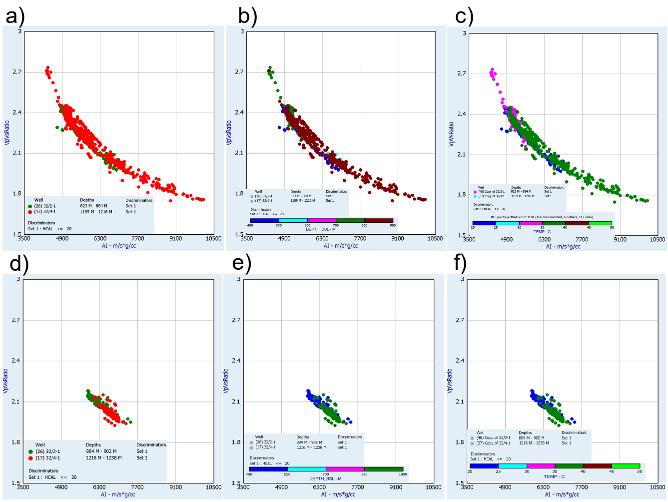

Figure 2 *P- to S-wave ratio (Vp/Vs) data plotted against the Acoustic Impedance (AI) from the two available wells within the Draupne Formation interval colour coded by well number (a). Same cross plot colour coded by depth and present day temperature (b &c). Draupne from deeper well (i.e. 32/4-1) has a wide AI distribution and is exposed to higher temperature. The Vp/Vs ratio data plotted against the AI from the same wells within the Heather Formation interval colour coded by well number (d). Same cross plot colour coded by depth and present day temperature (e &f). The Heather Formation data from both the wells show a limited AI distribution.*

The depleted pressure scenario was considered due to the possibility of pressure communication of the Sognefjord reservoir sandstone in Smeaheia area with the Troll Field. This could potentially result in CO_2 conversion from supercritical to gaseous state, thus reducing the storage capacity of the reservoir. The rock physics analyses were performed using Interactive Petrophysics (IP™), fluid replacement and AVO modelling were carried out on Hampson & Russell™ software, whereas the map generation were carried out employing Petrel™.

Case A-Heather Formation as Caprock

Assuming Heather Formation a good seal overlying the Sognefjord sandstone reservoir makes the interface a “soft event”, as the elastic properties (i.e. Density, Vp and Vs) decrease in Sognefjord at the Heather-Sognefjord contact represented by a trough (Figure 3a). The interface generated AVO class 4 anomaly (Rutherford & Williams 1989) (Figure 3b&c). The AVO curves and the resulting Intercept-Gradient plot register a significant change from scenario 1 to 2 (i.e. a jump from in-situ brine to 80% supercritical CO2 saturation). The scenario 2 and 3 points plot very close, indicating minor effect of patchy saturation at 12 MPa pressure and 38°C temperature (Figure 3c). A reduction in pressure and temperature to 5 MPa and 30°C (scenarios 4 & 5) caused a small increase in the gradient and increase in intercept (increase in negative value) due to CO_2 conversion from supercritical to gas form. The scenario 4 & 5 points plot slightly separated on the Intercept-Gradient plot indicating some influence of homogeneous compared to the patchy saturation at low pressure and temperature (Figure 3c).

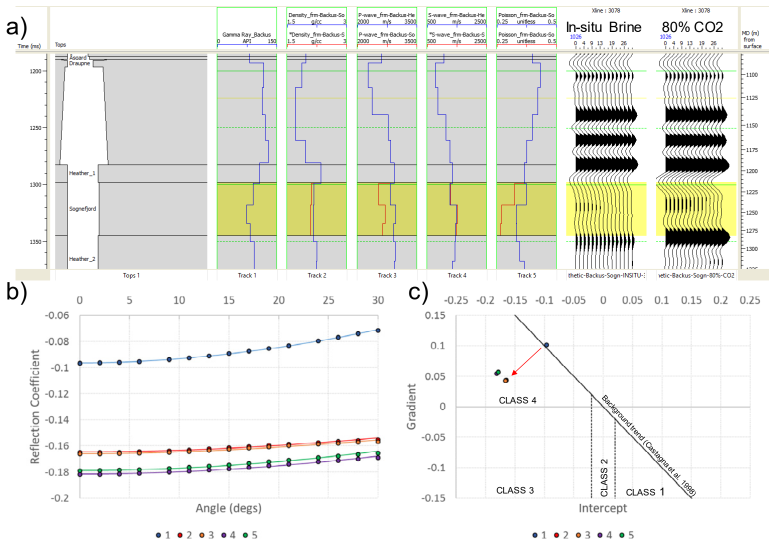

Figure 3 *The Sognefjord-Heather interface was modelled considering Heather Formation a cap rock. The change in elastic properties (i.e. Density, Vp, Vs and Poisson ratio) after fluid replacement (80% supercritical CO_2, homogeneous saturation, 12 MPa pressure and 38°C temperature in this example) are shown by red curves, whereas the blue curves represent the in-situ values (a). AVO curves showing scenarios from 1 to 5 (b). The AVO curves are class 4, which, and the resulting Intercept-Gradient plot show a significant jump from in-situ brine trend to 80% supercritical CO_2 saturation i.e. from scenario-1 to 2, however the subsequent scenarios (3-5) have caused small change in the AVO parameters (b&c).*

Case B-Draupne Formation as Caprock, CO_2 Accumulated in Heather Formation

Assuming the Heather Formation becoming more silty at places resulting in CO_2 accumulation in it. The Draupne Formation as caprock will make the interface a “hard event”, as the elastic properties (i.e. Density, Vp and Vs) increase in Heather Formation at the Draupne-Heather contact represented by a peak (Figure 4a). The interface generated AVO class 1 anomaly (Figure 4b&c) with in-situ brine case. The AVO curves and the resulting Intercept-Gradient plot show a significant change from scenario 1 to 2 i.e. a shift from in-situ brine to 80% supercritical CO_2 saturation (Figure 4b&c). The scenario 2 and 3 points plot close, indicating small difference of patchy and homogeneous saturations at 12 MPa pressure and 38°C temperature (Figure 4c). A reduction in pressure and temperature to 5 MPa and 30°C (scenarios 4 & 5) caused a fair decrease in both the intercept and gradient due to CO_2 conversion from supercritical to gas form. The scenario 4 & 5 points plot slightly separated on the Gradient-Intercept plot indicating some influence of homogeneous compared to the patchy saturation at low pressure and temperature (Figure 4c). All the gas-saturated points, however, indicate class 2 AVO anomalies.

Conclusions

The Sognefjord reservoir to Heather caprock interface produced class 4 AVO signatures, with a significant change in intercept and gradient with supercritical CO_2 (80%) substitution. A reduction in pressure and temperature to 5 MPa and 30°C caused a small increase in the gradient and increase in intercept (increase in negative value) due to CO_2 conversion from supercritical to gas form. The difference between patchy and homogeneous saturation was minor. The Heather reservoir to Draupne caprock interface yielded class 1 anomaly for in-situ brine case. The AVO curves and the resulting Intercept-Gradient plot showed a significant change from in-situ brine to 80% supercritical CO2 saturation falling in AVO class 2. A reduction in pressure and temperature to 5 MPa and 30°C caused a fair decrease in both the intercept and gradient due to CO_2 conversion from supercritical to gas form. The patchy to homogeneous scenario points plot slightly separated on the Gradient-Intercept plot indicating some influence of homogeneous compared to the patchy saturation at low pressure and temperature. All the gas-saturated points in this case indicated class 2 AVO anomalies.

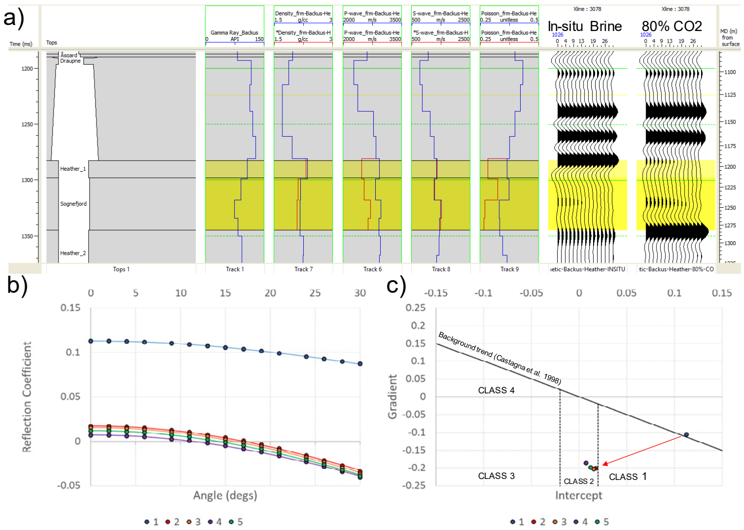

Figure 4 *The Heather-Draupne interface was modelled considering Draupne Formation a cap rock. The change in elastic properties (i.e. Density, Vp, Vs and Poisson ratio) after fluid replacement (80% supercritical CO_2, homogeneous saturation, 12MPa pressure and 38°C temperature in this example) are shown by red curves, whereas the blue curves represent the in-situ values (a). AVO curves are showing scenarios from 1 to 5 (b). The brine AVO curve is class 1, which, and the resulting Intercept-Gradient plot show a change to class 2 with significant jump from in-situ brine trend to 80% supercritical CO_2 saturation i.e. from scenario-1 to 2. The subsequent scenarios (3-5) have small influence on the AVO parameters and all points are plotting within class 2 (b&c).*

Acknowledgements

We are thankful for the support and funding provided by Research Council of Norway for the **OASIS (**Overburden Analysis and Seal Integrity Study for CO2 Sequestration in the North Sea) project (NFR-CLIMIT project #280472). We sincerely thank for the support and data provided by Gassnova and the Northern Light consortium. Academic software licenses have been provided by Lloyd's Register for Interactive Petrophysics, CGG for Hampson-Russell, and Schlumberger for Petrel.

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