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Reservoir Characterisation Of Johansen Formation As Potential CO2 Storage Reservoir In The Northern North Sea

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Summary

To evaluate subsurface reservoirs for CO2 sequestration, the grain scale properties and role of diagenesis is important for the injectivity and the subsequent mobilization. This study focuses on Johansen Formation of Jurassic age in the vicinity of Troll field within the northern North Sea. Johansen Formation is a saline aquifer and no hydrocarbon discovery has been reported in this reservoir so far. We analysed 24 wells using petrophysics and rock physics techniques to obtain net reservoir, net to gross ratio, effective porosity, volume of shale and level of cementation, and attempted to relate these parameters with the factors influencing them. The reservoir properties were found to be optimal approximately around depths shallower than 2000m (below sea floor, BSF). Even the shallowest sandstones exhibited cementation indicating calcite precipitation while the sediments deposited. Presence of shale however found to inhibit the quartz cementation possibly preserving the porosity. These findings will help understanding the complexity of the Johansen Sandstone as storage reservoir and the influence of heterogeneity on CO2 migration.



Introduction

This study highlights the petreophysics and rock physics evaluation of the early Jurassic reservoir sandstone (Johansen Formation) for its CO_2 storage potential in the northern North Sea. Norwegian authorities have been working for viability of large-scale (Gt storage potential) CO_2 storage sites in various parts of the Norwegian Continental Shelf. The area near Troll field is among one of those. Troll Field is situated approximately 80 km WNW of the city of Bergen. The Johansen sandstone reservoir is a saline aquifer with no hydrocarbon discovered so far in this area.

Our study area covers the Troll field in the south, extending towards north till the southern part of the Peon field (Figure 1a). The Johansen Formation are prograding and retrograding deltaic sands deposited during a lowstand (Marjanac 1995; Sundal et al., 2013). The gross thickness of the formation from the available wells ranged from 6m to 225m and the depth ranged from 1761m to 4101m (TVDSS) i.e. 1449m to 3693m below sea floor (BSF).



Figure 1 The study area is shown within the black rectangle. Troll Field is in the south eastern corner, whereas the Peon discovery lies in the NNW. The available wells (a total 24) considered in the study were drilled in and around the Troll field. Cross sections are marked by pink, dark blue and green lines (a). Johansen Formation depth map generated using the well tops. The depths are from sea floor (BSF), and found to be increasing towards north west (b).

The CO_2 storage is normally extended to a large area, whereas, the borehole data if available represents only the structural highs. Therefore, it is important to analyse the seismic data in order to be able to predict the reservoir properties where wells are not present. This study attempts to investigate the reservoir properties and the factors that could influence improving or are detrimental to a reservoir using the wellbore data.

Method and/or Theory

A total of 24 wells were available for the study. Three lithostratigraphic/structural correlation profiles (Figure 2, see Figure 1a for location) were made using tops from Norwegian Petroleum Directorate Fact Pages (NPD, 2018). Reservoir parameters such as total porosity (PHIT), effective porosity (PHIE), volume of shale (Vsh) and net-to-gross ratio (N/G) were obtained from the Petrophysics



analysis. Vsh was calculated using gamma ray employing the "old rock" method (Larionov, 1969). Total and effective porosity were computed using the combination of density (RhoB) and neutron (NPHI) logs acquired in 21 wells. Absence of one or other log in rest of three wells prompted us to calculate porosity using the other available logs (e.g. sonic-NPHI combination). The net reservoir was computed using cut-offs PHIT >= 0.8 and Vsh =< 0.4. In addition, a rock physics analysis of five wells was carried out to investigate the physical and elastic properties of the Johansen sandstone. Out of five wells, three were selected from the shallow part, and two from the deeper part of the basin (Figure 2a). Maps were plotted on the basis of arithmetic average of properties obtained from the petrophysics analysis (Figure 1b). Petrophysics and rock physics analyses were performed using Interactive Petrophysics (IPTM) software, whereas the lithostratigraphic/structural cross-section and map generation were carried out employing PetrelTM.



Figure 2 Structural cross section along X-sections 1, 2 & 3 correlating top and bottom of the Johansen Formation. The formation is getting deeper towards north west. The red arrows plotted on the X-section 1 indicate the five wells used for rock physics analysis (a). Average effective porosity map generated using the petrophysics analysis data, the porosity improves southwards (b).

Examples

Plotting the Johansen Formation tops from the wells reveals that the basin is deepening towards north west (Figure 1b). The reservoir properties such as the average effective porosity (PHIE) is improving towards the shallower part of the area in the south (Figure 2b), that can further be confirmed by plotting the PHIE against depth (Figure 3a). Generally, the sandstones are cleaner at shallow depths as evident by the points colour coded by Vsh. The net-to-gross ratio (N/G) also shows a negative correlation with depth (Figure 3b). Furthermore, both the gross and net thicknesses show a weak negative correlation with the depth i.e. the thicknesses decrease with increase in depth (Figures 3c&d), however a large data scatter shows that the proximity to source is not the only factor controlling the thickness, but basin geometry is also important. These parameters indicate that the overall reservoir quality deteriorates as we go deeper in the basin because of change in facies, as well as possible quartz cementation.

Comparing the effective porosity (PHIE) with the P-wave velocity (Vp) show that the wells which are deeper and have exposed to higher temperature have lower porosities with high Vp (Figures 4a,b&c). This can be attributed to chemical compaction resulting in reduction of porosity due to quartz



cementation (Bjørlykke and Egeberg 1993). Nearly all the wells show points plotting towards higher Vp above the main trend of the data cluster. This may indicate discrete laminations with calcite cementation, which reduce porosity and significantly increase the Vp (Figure 4).



Figure 3 Average effective porosity of reservoir sandstone (Johansen Formation) from 24 wells plotted against depth below sea floor (BSF). As expected, the porosity decreases with increasing depth. The points are colour coded by shale volume (Vsh), which show a relatively cleaner reservoir at shallower depths i.e. above 2000m BSF (a). The net-to-gross ratio (N/G) of the reservoir also decreases with depth (b). A weak negative correlation exists between both the gross and net thickness values and depth, however the wide data scatter signifies the influence of basin geometry in addition to the sediments source proximity (c&d).

The very high velocity data points at temperature 50° - 70° C likely indicate that the reservoir had gone through shallow carbonate cementation possibly due to dissolved and re-precipitated carbonate of biogenic origin (Bjørkum and Walderhaug 1990). However, we did not observe the characteristic high resistivity spikes associated with calcite laminations in the studied five wells.

Analysing Figure 4d reveals that the quartz/silica cementation is more pervasive in the cleaner sandstones, whereas sandstones with Vsh \sim 30-40% are least cemented. Chlorite is an important component of many clays present in shales, and chlorite coated quartz grains are common in the samples from the Johansen Formation (Sundal et al., 2013). The chlorite coating on detrital quartz grains prevents the pore water contact with quartz surface, and provides the mechanism to preserve porosity by inhibiting quartz overgrowths during deep burial (Ehrenberg, 1993).

Conclusions

Within the study area the Johansen Formation reservoir sandstone quality is improving towards south at shallower depths approximately above 2000m (BSF) exhibiting high porosities, high N/G ratio and low Vsh. The rock physics analysis shows possible calcite laminations and cementation in reservoirs including the zones at shallow depths (i.e. less than 2000m BSF). Quartz cementation was observed with increase in depth. Comparatively shaly sandstones exhibit low quartz cementation level possibly due to presence of chlorite inhibiting the quartz precipitation.

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Figure 4 Effective porosity (PHIE) plotted against the P- wave velocity (Vp) from the five selected wells. The outliers with high Vp possibly indicate calcite laminations (a). Same cross plot colour coded by depth, present day temperature and volume of shale (Vsh) (b, c &d). The reservoir that was exposed to higher temperature for being deeper exhibit higher Vp. The data from low temperature (50-70°C) zone showing high velocity (blue dots) likely indicate carbonate cementation at shallow depths (b). Cross plot shows low quartz cementation level in sands, which possess higher Vsh values, the red arrow indicates increase in cementation level (d). This observation signifies the role of clays inhibiting the quartz cementation. (Effective porosity units are fraction/decimal).

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