Tu_R02_02

Comparison of Sealing Properties of Amundsen and Drake Formations for Potential CO2 Storage in North Sea

M. Fawad[1], N.H. Mondol[1,2]*

[1] University of Oslo; [2] Norwegian Geotechnical Institute (NGI)

Summary

Seal evaluation for CO2 storage is different from that of a hydrocarbon trap since the oil or gas accumulation itself validates the cap-rock integrity. However, in case of subsurface CO2 storage a careful investigation is required to avoid any risk of potential seal failure. The Johansen Formation of Early Jurassic age in and around the Troll field is a potential CO2 storage reservoir in the northern North Sea. It is enveloped by Amundsen mudstone, whereas in the southeast where the Amundsen cap pinches out, the Drake mudstone Formation directly overlies the Johansen Formation. We evaluated wireline log data from 24 exploration wells using petrophysical analysis and rock physics diagnostics to obtain present day depth, thickness, temperature, volume of clay, physical and elastic properties to evaluate the seal integrity of the Amundsen and Drake Formations. The sealing properties of both the formations were found to be within acceptable range, with minor presence of brittle zones at deeper levels within the Drake Formation containing low volume of shale. These findings will help understanding the seal integrity of Amundsen and Drake Formations as cap-rocks above the Johansen Sandstone being a potential CO2 storage reservoir.

Introduction

This study deals with the petrophysics and rock physics evaluation of the early Jurassic Amundsen and Drake Formations for their sealing potential above the Johansen Formation as a possible CO_2 storage reservoir (Fawad and Mondol, 2018) in the northern North Sea. The Norwegian government have been working on feasibility of large-scale (Gt storage potential) CO_2 storage sites in various parts of the Norwegian Continental Shelf. The area near and around Troll field is among one of those. Troll field is situated approximately 80 km WNW of Bergen in Norway (Figure 1a). The Johansen Formation sandstone reservoir is a saline aquifer with no hydrocarbon reported so far in this area.

The study area covers the Troll field in the south, extending towards north covering the southern part of the Peon field (Figure 1a). The potential reservoir sandstones of Johansen Formation are prograding and retrograding deltaic in nature deposited during a lowstand (Sundal et al., 2013). The Amundsen Formation mudstones, which enclose the Johansen Formation consist of light to dark grey, non-calcareous siltstones and shales, in part carbonaceous and pyritic. The Drake Formation overlies the Cook Formation sandstone in most of the area, however it directly overlies the Johansen Formation where the Amundsen mudstone pinches out in the southeast (Figure 2c). The Drake Formation consists of medium grey, slightly sandy, calcareous, and silty claystone. The upper part is dark grey to black, fissile, micaceous shale containing calcareous nodules. Some fine to coarse sandstones are present in the formation within the study area (Figure 1b, NPD, 2019).

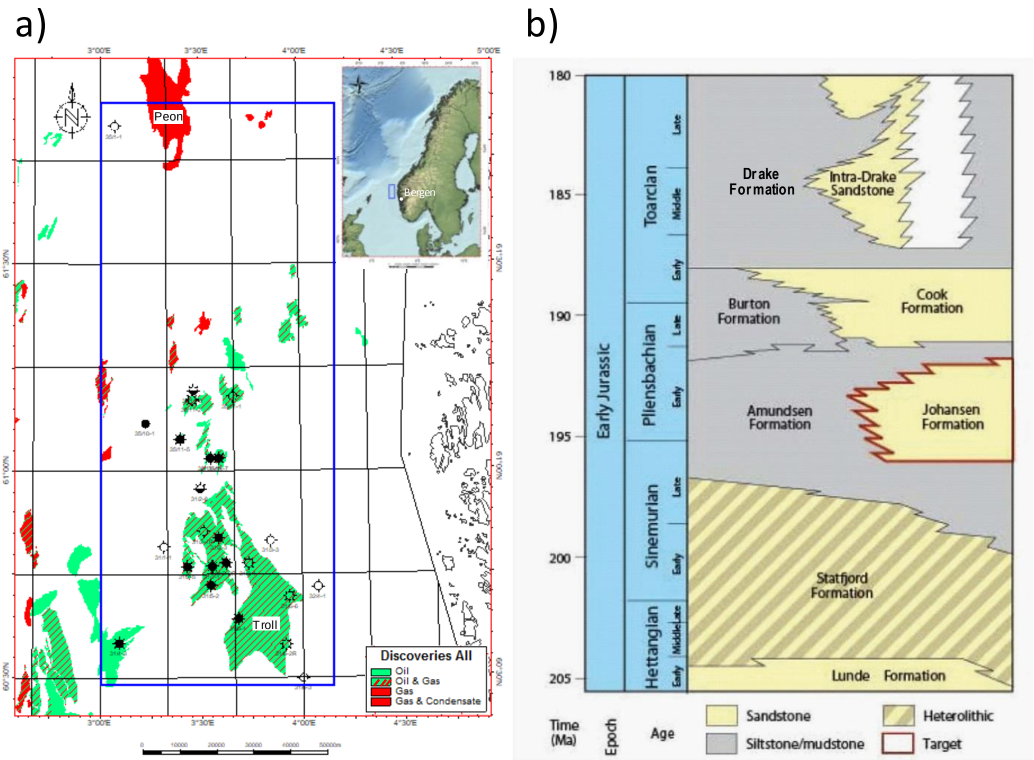

__Figure 1__ The study area lies within the blue rectangle. Troll Field is in the southeastern corner, whereas the Peon discovery is situated in the NNW. The available wells (a total 24) used in the study were drilled in and around the Troll field (a). A succession shows the stratigraphic positions of the Amundsen, Drake and Johansen Formations within the area of study (Sundal et al., 2013) (b).

The depth of Amundsen Formation from the available wells ranged from 1969 to 4157 m (TVDSS), whereas the Drake Formation depth ranged from 1810 to 3790 m (TVDSS). The CO_2 storage is normally stretched to a large area, however, the borehole data represents only the structural highs. Therefore, usage of seismic data is planned to predict the elastic properties in next phase. This paper represents the sealing properties of the Amundsen and Drake Formations and the factors that could influence improving or are detrimental to the seal integrity using the well log data.

Methods

From the available 24 wells, three lithostratigraphic/structural correlation profiles (Figures 2a&b) were made using formation tops from the Norwegian Petroleum Directorate Fact Pages (NPD, 2019). The volume of clay (VCL) were obtained from the petrophysics analysis using both gamma ray employing the "old rock" method (Larionov, 1969), and the combination of density (RhoB)/ neutron porosity (NPHI) logs acquired in 21 wells. Temperature at each zone was interpolated from the bottom hole temperature (BHT) data. In addition, a rock physics analysis of seven wells was carried out to investigate the elastic properties of the Amundsen and Drake Formations. The wells for rock physics analysis were selected to obtain information at various depths (Figure 2a). Maps were plotted based on thickness obtained from correlations (Figures 2c&d), and parameters obtained from the petrophysics analysis. Only one well i.e. 31-1/1 contained an acquired shear wave velocity (Vs) log. Greenberg & Castagna (1992) method was employed to compute synthetic Vs logs using the neutron-density derived volume of clay (VCLND) input. Petrophysics and rock physics analyses were performed using Interactive Petrophysics (IP™) software, whereas the cross-section and map generation were carried out employing Petrel™.

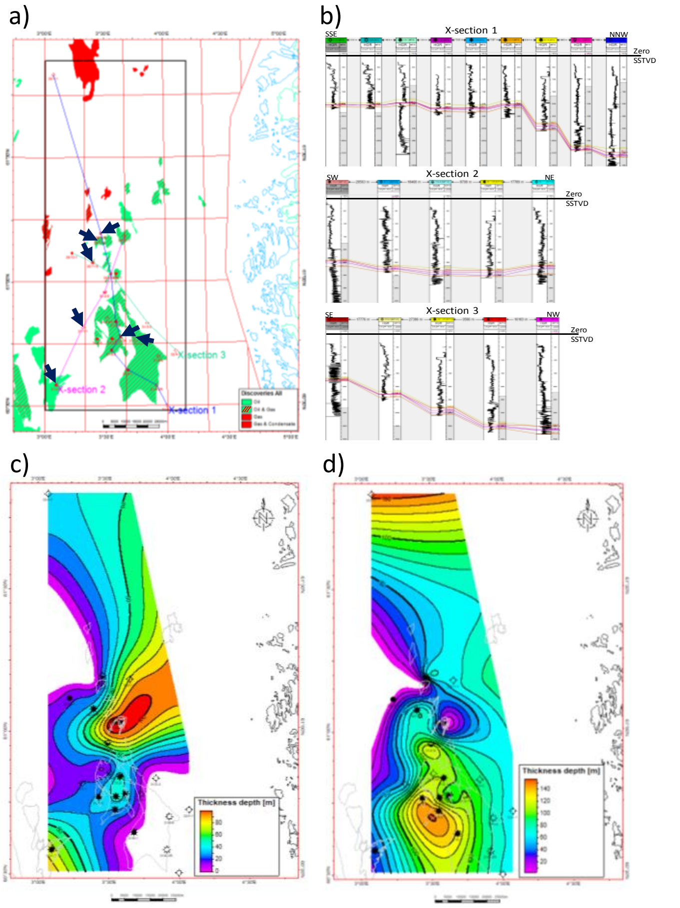

Figure 2 *Locations of the cross sections marked by pink, dark blue and green lines on the map with 7 wells selected for the rock physics analysis indicated by dark blue arrows (a). The Structural cross section along X-sections 1, 2 & 3 correlating top and bottom of the Johansen, Amundsen, Cook and Drake Formations. The strata is getting deeper towards north and northwest. (b). Depth thickness map show Amundsen Formation pinches out in the northwest and southeast, with depocenter lying eastwards in middle of the area (max thickness ~100m)(c), whereas the Drake Formation pinches out towards west with depocenter situated in the south (max thickness ~140m), the formation thickness also increases in the north towards deeper levels (d).*

Results and Discussion

From the petrophysics analyses, it was evident that the volume of clay showed a weak positive correlation with depth. As expected, the bottom hole temperature (BHT) increased with depth while Amundsen Formation experienced a maximum temperature of 140°C, whereas the Drake Formation had undergone a maximum temperature of 136°C. Using the template proposed by Perez and Marfurt (2014), we plot Poisson's ratio (ν) and Young's modulus (E) corresponding to the Amundsen and Drake Formations data from the 7 selected wells (Figure 3). The data spread for both the Amundsen and Drake Formations is similar, with slightly more data points from deeper levels falling within the brittle zone in case of Drake Formation (Figure 3a), the data points experienced high temperature (Figure 3b), and contain low volume of shale (Figure 3c). Majority of data, both from Amundsen and Drake Formations plot within less ductile to less brittle zone depicting a low risk of fracturing.

Perez and Marfurt (2014) demonstrated that LambdaRho–MuRho rock physics templates had been very useful for lithology characterisation and correlating brittleness to rock properties. Using this template for the three most common minerals in the area of study i.e. quartz, clay and calcite as a reference

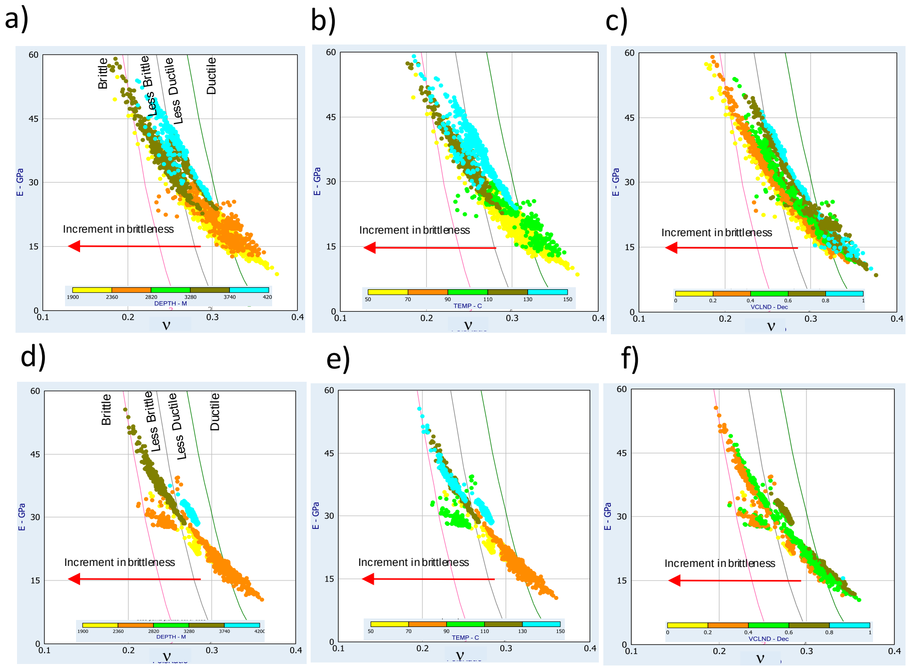

Figure 3 *Poisson's ratio (ν) versus Young's modulus (E) crossplot with Drake Formation data from 7 selected wells colour-coded with depth (a), temperature (b), and volume of clay (c). Same crossplot with Amundsen Formation data from the said wells colour-coded with depth (d), temperature (e), and volume of clay (f).*

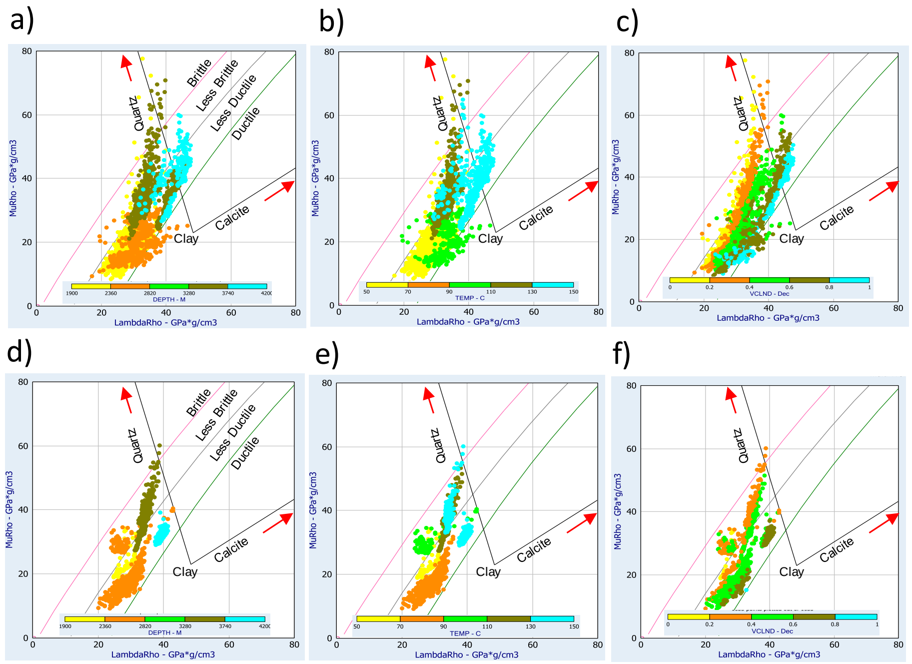

Figure 4 *The LambdaRho – MuRho crossplot with Drake Formation data from 7 selected wells colour-coded with depth (a), temperature (b), and volume of clay (c). Same crossplot with Amundsen Formation data from the said wells colour-coded with depth (d), temperature (e), and volume of clay (f).*

(Perez and Marfurt, 2014), the LambdaRho–MuRho well log results were crossplotted corresponding to the Amundsen and Drake Formations from the 7 selected wells (Figure 4). The plot show a wide LambdaRho spread in case of Drake Formation compared to that of Amundsen Formation (Figure 4a&d). Data from the deeper levels show high MuRho values, the brittleness seems to be increasing with zones experiencing higher temperature (Figure 4b&e), however as the volume of shale (VSHND) increase even the points from deeper zones fall away from brittle zone within the less ductile zone (Figure 4c&f). Deep and quartz rich zones within the Drake Formation plot within the brittle zone (Figure 4a&c). Generally, data from both the Amundsen and Drake Formations fall within less ductile to less brittle zone reflecting a low risk of fracturing.

The amount of strain a material can withstand prior to brittle failure depends on its ductility (Ingram and Urai, 1999). Ductility is a function of many factors i.e. lithology, confining pressure, pore pressure, temperature, and differential stress/strain ratio (Davis and Reynolds, 1996). In sedimentary basins, the higher confining pressure is attained by increasing burial depth. Furthermore, the temperatures approximately above 60-80°C lead to the onset and progress of chemical compaction processes resulting in stiffening and embrittlement of the rock. The rock physics analyses of the Amundsen and Drake Formations confirmed that the increase in brittleness owed to the increase of quartz content, depth and temperature. In mudstones primarily saturated with brine, the computed S-wave velocity normally works within acceptable limits. Though both the formations lack a significant amount of organic rich matter, however, the usage of synthetic S-wave velocity (Vs) might have dampened the organic content effect, in addition to the influence of calcite/dolomite.

Conclusions

Within the study area the Amundsen and Drake Formation brittleness increase with depth and temperature, whereas decrease with increase in volume of clay. In the wells analysed, some quartz rich deeper levels within the Drake Formation fall within the brittle zone, however, the majority Amundsen and Drake Formation data plot in between less ductile to less brittle zone showing low possibility of fracturing. The usage of synthetic Vs has limitations, as the influences of organic rich matter and/or carbonates are dampened in the analyses.

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 are indebted 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, and Schlumberger for Petrel.

References

Davis, G.H., Reynolds, S.J., Kluth, C.F. & Kluth, C. [2011] *Structural Geology of Rocks and Regions*. John Wiley & Sons.

Fawad, M. & Mondol, N.H. [2018] Reservoir Characterisation of Johansen Formation as Potential CO2 Storage Reservoir in the Northern North Sea. In: *Fifth CO2 Geological Storage Workshop.*

Greenberg, M.L. & Castagna, J.P. [1992] Shear-wave velocity estimation in porous rocks: Theoretical formulation, preliminary verification and applications. Geophysical prospecting, **40**, 195–209.

Ingram, G.M. & Urai, J.L. [1999] Top-seal leakage through faults and fractures: the role of mudrock properties. *Geological Society, London, Special Publications*, **158**, 125–135.

Larionov, V.V. [1969] Radiometry of boreholes. *Nedra, Moscow*, 127.

NPD. [2019] Norwegian Petroleum Directorate Fact pages of exploration wellbores. Available from http://factpages.npd.no/factpages/.

Perez, R. & Marfurt, K. [2014] Mineralogy-based brittleness prediction from surface seismic data: Application to the Barnett Shale. *Interpretation*, **2**, T255–T271.

Sundal, A., Nystuen, J.P., Dypvik, H., Miri, R. & Aagaard, P. [2013] Effects of geological heterogeneity on CO2 distribution and migration–a case study from the Johansen Formation, Norway. *Energy Procedia*, **37**, 5046–5054.