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Mineralogy analysis of Jurassic reservoir sandstones using wireline log data in the northern North Sea

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Summary

In a hydrocarbon accumulation, the viability of the reservoir and the caprock is well established; however, a subsurface CO_2 storage requires preliminary studies to reduce the risk of poor reservoir quality and the overlying seal integrity. While evaluating a potential reservoir for geological CO_2 sequestration, studying the influence of mineralogy, diagenesis, porosity, permeability, and reservoir fluids is essential. The thin section studies, scanning electron microscopy (SEM) and X-Ray Diffraction (XRD) are valuable tools to investigate the mineralogy of reservoir rocks. However, the well-log data with the application of specific crossplots also help to determine various lithologic reservoir characteristics. The Upper Jurassic Sognefjord Formation sandstone is the main oil and gas reservoir in the Troll Field. Besides, the Middle Jurassic Fensfjord and occasionally Krossfjord Formation sandstones are hydrocarbon-bearing in this area. The Heather Formation mudstone exhibits an interfingering stratigraphic relationship with the Krossfjord, Fensfjord, and the Sognefjord Formations, finally overlain by the Draupne Formation organic-rich shales. The Sognefjord, Fensfjord, and Krossfjord Formations are the potential CO_2 storage reservoirs in the proposed CO_2 storage site Smeaheia (east of the Troll field). We evaluated wireline log data from four exploration wells where the spectral gamma-ray was acquired. Based on this data, we investigated the Sognefjord, Fensfjord, and Krossfjord Formation sandstones in terms of the mineralogy, type of clays, and additional detrital components. We will integrate these findings with the existing data, and our ongoing laboratory studies to understand the reservoir quality of the Krossfjord, Fensfjord and the Sognefjord Formations for CO_2 storage.

Introduction

This study deals with the petrophysical evaluation of the Middle Jurassic Krossfjord, Fensfjord, and Upper Jurassic Sognefjord Formations for their suitability as possible CO_2 storage reservoirs in the Smeaheia area (east of Troll field) in the northern North Sea (Fig. 1a). The Norwegian government is working to establish a large-scale (Gt storage potential) CO_2 subsurface storage site on the Norwegian Continental Shelf (NCS). This research is one of several multidisciplinary studies to evaluate the viability of such CO_2 storage sites (Fawad and Mondol, 2018). The study area covers the Troll field and its satellites on the Horda Platform. The Troll field is located approximately 80 km WNW of Bergen, Norway. The Smeaheia area is among the few of the potential CO_2 storage candidates under consideration. Fig. 1b shows a Jurassic and Lower Cretaceous stratigraphic succession in the study area. The main prospective reservoir is the Sognefjord Formation, which consists of coastal-shallow marine sands, overlain by the Heather and Draupne Formation shales, the main caprocks in the area. The Sognefjord sands are medium to coarse-grained, well-sorted, and friable to unconsolidated, locally weakly micaceous, and minor argillaceous. The Heather Formation interfingers with sandstones of the Krossfjord, Fensfjord, and Sognefjord Formations. It consists mainly of silty claystone with thin streaks of limestone, occasionally becoming highly micaceous grading into sandy siltstone (NPD, 2020). The Krossfjord Formation is medium to coarse-grained, well-sorted, and loose to very friable sandstone. The Fensfjord Formation is fine to medium-grained, well-sorted, and moderately friable to consolidated sandstones with minor shale intercalations. Bioclastic material and occasional cemented bands occur in all the three Krossfjord, Fensfjord, and Sognefjord Formations. The Draupne formation comprises of dark grey-brown to black, usually non-calcareous, carbonaceous, at places fissile claystone. It is characterized by very high Gamma-ray radioactivity (often above 100 API units), because of organic carbon content. The Draupne Formation deposited in a marine environment had restricted bottom circulation, mostly under anaerobic conditions (NPD, 2020). The Gamma Ray and Spectral Gamma Ray (Potassium, Thorium, and Uranium content) logs from well 31/6-1 are presented in Fig. 1c.

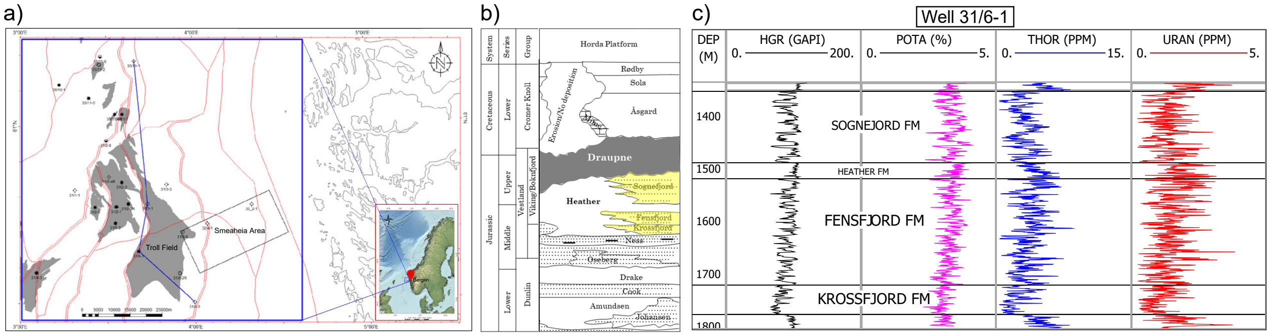


Figure 1: a) The study area lies within the blue rectangle; a SSE-NNW line (A-A') connects the wells selected for this study within, and around the Troll field. (b) A generalized Jurassic and Lower Cretaceous stratigraphic succession in the study area (modified from NPD CO_2 Atlas, 2014). The potential reservoir sandstones are highlighted in yellow color. (c) Gamma Ray and Spectral Gamma Ray (Potassium, Thorium, and Uranium content) curves from well 31/6-1.

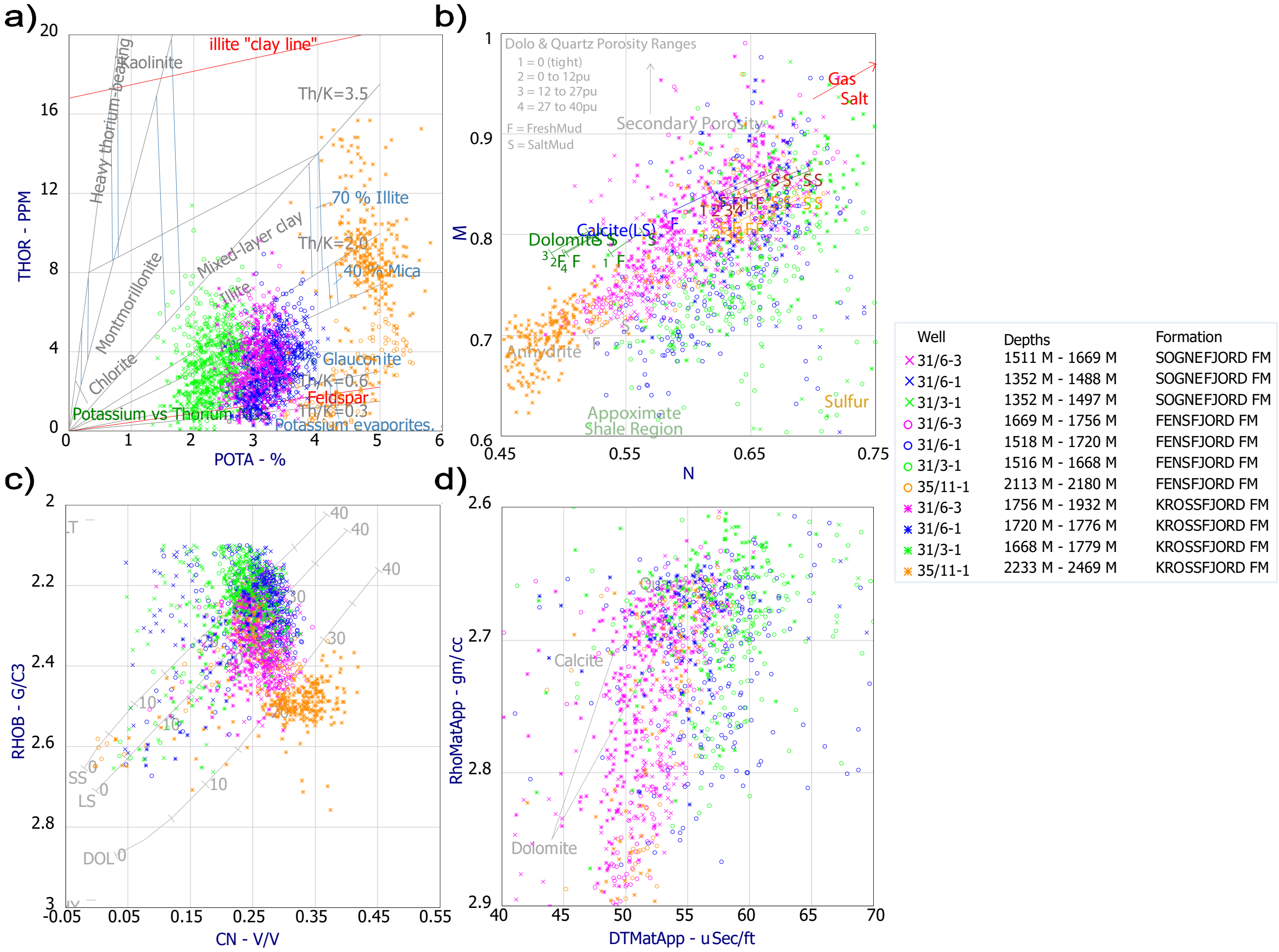
The available well log data represents only sporadic information; however, the CO_2 storage covers a large area. Therefore, it is essential to consider all factors that can affect the reservoir quality both laterally and vertically. This study aims to evaluate the reservoir rock composition, with possible detrital and diagenetic mineral assemblages using petrophysics crossplot techniques. This information will help find the factors, which could influence the quality of a CO_2 storage reservoir.

Theory and Method

We selected four wells (31/6-3, 31/6-1, 31/3-1, and 35/11-1) based on the presence of Spectral Gamma Ray (SGR) logs from the available data. The Spectral Gamma Ray log is commonly used for recognizing clay mineral types and clay mineral volume estimation. We made potassium-thorium crossplots, which are handy for the identification of clay minerals and the separation of micas and K-feldspars. In the crossplot, the lines radiating from the origin possess gradients matched with values (Doveton, 1994). Another crossplot of *N* versus *M* is used for lithology determination, lithology trends, gas detection, and clay mineral classification (Fertl, 1981). The *N* and *M* are the mineralogy indicators. The 'Rho matrix apparent' and 'DT matrix apparent', were obtained using Interactive Petrophysics (IP™) software, which we also employed to generate the crossplots (Fig. 2). For matrix calculations, we selected the neutron tool 'CNL', and 'Wyllie' method. The cross-section and map generation was carried out using Petrel™.

Results and discussion

The well 31/3-1 has low potassium content (~2-2.5%) for all the three Sognefjord, Fensfjord, and Krossfjord Formations. On the other hand, the well 35/11-1 has the highest Potassium content (~4-5%) for the Fensfjord and Krossfjord Formations (Fig. 2a). Sognefjord Formation is not present in well 35/11-1. The mineralogy from the Potassium-Thorium crossplot of the Sognefjord, Fensfjord, and Krossfjord Formations in the respective well is approximately the same with a minor difference. Only in well 35/11-1 the Krossfjord Formation is micaceous, whereas the Fensfjord sands are glauconitic to Felspathic. In well 31/3-1, there is minor Chlorite in the Fensfjord Formation; however, the Illite, Mica, Glauconite, and Feldspar are present in all the three, Sognefjord, Fensfjord and Krossfjord Formations.



Well	Depths	Formation
× 31/6-3	1511 M - 1669 M	SOGNEFJORD FM
× 31/6-1	1352 M - 1488 M	SOGNEFJORD FM
× 31/3-1	1352 M - 1497 M	SOGNEFJORD FM
○ 31/6-3	1669 M - 1756 M	FENSFJORD FM
○ 31/6-1	1518 M - 1720 M	FENSFJORD FM
○ 31/3-1	1516 M - 1668 M	FENSFJORD FM
○ 35/11-1	2113 M - 2180 M	FENSFJORD FM
✱ 31/6-3	1756 M - 1932 M	KROSSFJORD FM
✱ 31/6-1	1720 M - 1776 M	KROSSFJORD FM
✱ 31/3-1	1668 M - 1779 M	KROSSFJORD FM
✱ 35/11-1	2233 M - 2469 M	KROSSFJORD FM

Figure 2: Data points of Sognefjord, Fensfjord, and Krossfjord Formations from the wells 31/6-3, 31/6-1, 31/3-1, and 35/11-1 on (a) Potassium vs. Thorium crossplot with (Schlumberger^{TM}) mineral classification overlay, (b) N vs. M crossplot with (Schlumberger^{TM}) mineral classification overlay, (c) Neutron porosity vs. bulk density (RHOB) crossplot with a typical mineral-trend overlay, and (d) A 'DT matrix apparent' vs. 'RHOB matrix apparent' crossplot with three-mineral (ternary) overlay.

In the N-M crossplot (Fig. 2b), data from all three wells show a wide scatter falling within Quartz to the Calcite trend. The three sandstones (Sognefjord, Fensfjord, and Krossfjord Formations) in well 31/6-3 show a range from Sandstone to Calcite. In well 35/11-1, both Fensfjord and

Krossfjord data points pull towards Anhydrite zone, whereas in wells 31/3-1 and 31/6-1, mainly the Fensfjord Formation data points pull towards Shale region in the crossplot.

The neutron-density crossplot (Fig. 2c) shows that in wells 31/3-1 and 31/6-1, all the three Formations (Sognefjord, Fensfjord, and Krossfjord) exhibit high porosities (~30%). Porosities drop down in the sandstones approximately to 25% in well 31/6-3. In wells 31/3-1 and 31/6-1, the data points pulling the cluster towards the Limestone trend indicate some calcite cementation or lamination. The deepest well (35/11-1) show comparatively low porosities (average ~20%), and a wide range of data scatter from the Quartz sand trend to the Dolomite trend. This scatter could be because of the presence of high-density Glauconite in addition to Calcite.

Most of the sandstones are within the mechanical compaction zone owing to their present shallow depth (less than 2000m). Only the Fensfjord and Krossfjord Formations in the deepest well (35/11-1) could have been exposed to the early stages of chemical compaction (quartz cementation). There is no Chlorite content in these formations in this well (Fig. 2a); therefore, we do not expect any inhibition of quartz cement precipitation due to the presence of Chlorite (Ehrenberg, 1993). In the “DT apparent matrix” versus “RHOB apparent matrix” crossplot (Fig. 2d), a part of the data plots along the Quartz-Calcite leg of the triangle indicating calcite cementation or laminations. The points plotting to the south of the three-mineral triangle could be due to the presence of Glauconite, and to some extent, Mica.

Conclusions

The petrophysical analysis of four selected wells reveals that mostly the Sognefjord, Fensfjord, and Krossfjord Formation sandstones are at shallow depths (mechanically compacted zone) and therefore retaining high porosities. Only the deeper Fensfjord and Krossfjord Formations have exposed to the early stages of quartz cementation. We expect no quartz cement inhibition in the deeper zones because of the absence of Chlorite content. Mica and Feldspar contents are dominant in the deeper zones (in well 35/11-1). Calcite cementation or laminations are evident from all the well data. We will correlate these results with the existing laboratory data, and our ongoing mineralogical and geochemical analyses.

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