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Petrophysical Analysis And Rock Physics Diagnostics Of Sognefjord Formation In The Smeaheia Area, Northern North Sea

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Summary

This study focuses on petrophysical characterization and rock physics diagnostics of the reservoir sandstones of Sognefjord Formation in the Smeaheia area that penetrated by an exploration well 32/4-1. The large scale CO2 storage site “Smeaheia” is located east of the Troll field in the Stord Basin. The CO2 storage formation is identified within a fault block bounded by major faults to the north, east and west, where the faults system in the east is the Øygarden Fault Complex and the fault to the west and north is the Vette Fault. The storage formation has pinched out towards the south. Petrophysical analysis and rock physics diagnostics suggest that the reservoir sandstone is uncemented and has good to excellent reservoir quality. The reservoir sandstone can be subdivided into three zones where the lower unit (Zone-3) has an excellent reservoir quality (high porosity, high permeability and less clay content) compared to the upper unit (Zone-1 and Zone-2). The two carbonate stringers are present in Zone-3 interpreted as extremely high resistivity, high density, high Vp and low porosity/permeability units which could be flow barriers based on their lateral extent.

Introduction

Earth being an oasis in the vast, barren known space has a delicate balance of climate and temperature. Reduction of CO_2 emissions in the atmosphere is the key to restore and sustain this balance that has been disturbed due to extensive usage of fossil fuels especially within the last two centuries. Sequestration of human generated CO_2 in depleted oil and gas reservoirs and in other appropriate geologic formations (e.g., saline aquifers, coal seams etc.) is one of the many solutions for reducing CO_2 impact on atmosphere. Governments and the industry are interested in determining the feasibility, risks, and best possible sites for sequestering CO_2 in the subsurface. The Smeaheia area has recently been evaluated by Equinor in the North Sea as a potential large scale CO_2 storage site. The feasibility study has mapped two structures (Alpha-32/4-1 and Beta-3/2-1) in the area, which both are large enough to inject 1.3Mt CO_2 per year over a 25 year period. Reservoir simulations indicate that the Alpha and Beta structures have a potential storage capacity of roughly 100Mt each and there is no risk of CO_2 migrating/contaminating into the Troll reservoir. The aim of the study is to investigate properties of the reservoir sandstone of Sognefjord Formation penetrated by an exploration well (32/4-1) at crest of the Alpha structure (Fig. 1a). The reservoir sandstone is identified as a fault block bounded by the Vette Fault to the west and north-west and the Øygarden Fault Complex in the east (Fig. 1a). The Sognefjord sandstone dies out towards the south.

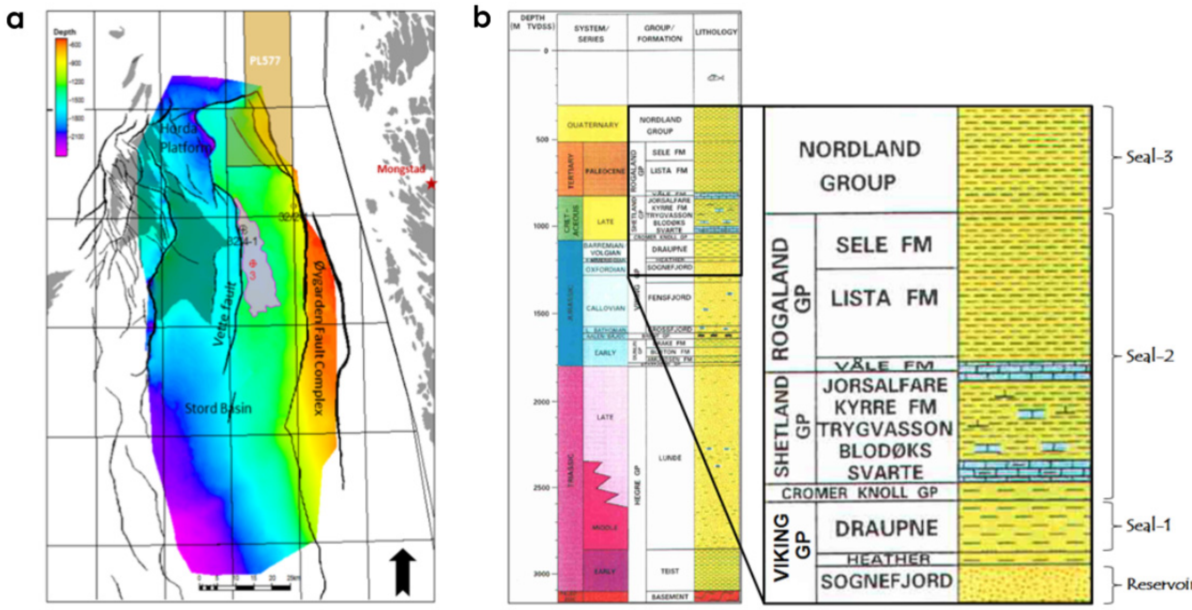

Figure 1 *a) Top Sognefjord Formation depth and structural map (Alpha-32/4-1, Beta-32/2-1) with the suggested CO_2 injection location (#3) and plume migration after approximately 500 years (adapted from Gassnova 2013) and b) Stratigraphic column of well 32/4-1 (Alpha Structure) showing the target CO2 storage reservoir of Sognefjord Formation and its primary, secondary and tertiary seals (Source: NPD FactPages).*

The Smeaheia area is approximately 20km east of the Troll field and situated in the Stord Basin of water depth about 320m and is structurally shallower than the Troll field (Fig. 1a). Well 32/4-1 penetrated 68m of Sognefjord Formation sands, while well 32/2-1 had 114m of Sognefjord Formation sands. The main cap rock covering the Sognefjord reservoir sandstone is the Upper Jurassic Draupne Formation which is a marine, organic rich, impermeable claystone (Fig. 1b). Secondary seal units are present in the form of cretaceous limestone and shales belonging to the Shetland and Cromer Knoll groups. Tertiary and Quaternary deposits are also assumed to have sealing capacity. Preliminary estimations of pressure build-up and estimations of safe pressure at shallowest point of plume migration, indicates that the area will have capacity to safely store 3.2MT/yr CO2 over 50 years which gives a pressure build-up of 25 bars for the base case pore volume.

Materials and Methods

A suite of well log data (Figs. 2b-e) from the exploration well 32/4-1 (Alpha structure) is utilized for petrophysical analysis and rock physics diagnostics to characterize the reservoir sandstones (Sognefjord Formation). Based on mineralogical composition (Martin and Lowrey, 1997) and petrophysical log responses, the Sognefjord Formation is subdivided into three reservoir zones; a) Zone-1 (1238-1251.30m), b) Zone-2 (1251.30-1266.80m) and c) Zone-3 (1266.80-1306m) interpreting as subarkosic arenite, arkosic arenite and lithic arenite respectively (Fig. 2a). To calibrate and to validate results of petrophysical analysis and rock physics diagnostics, the data and relevant information of core analysis presented in the report (Martin and Lowrey, 1997) are utilized. Sedimentology and petrography analyses of approximately 41m of conventional cores of the Heather and Sognefjord Formations are presented in the report. The shale volume in reservoir sandstones is calculated using gamma ray log employing Lariovon (1969) 'younger rock' method (Fig. 3a). Apart from measured neutron porosity (NPHI), the density and sonic logs are utilized to calculate density porosity (DPHI) and sonic porosity (PHIT) of the reservoir sandstone (Fig. 3b). Petrophysics analysis and rock physics diagnostics were carried out using Interactive Petrophysics (IP™) and Hampson Russel (HRS™) softwares.

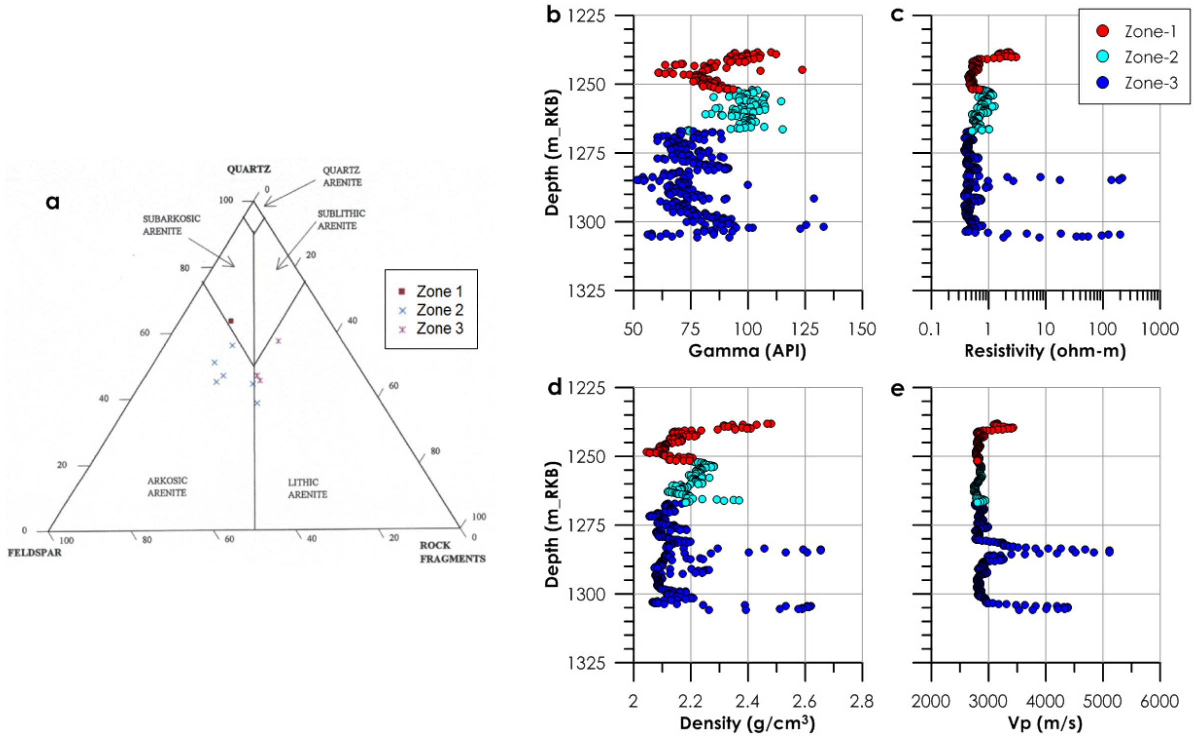

Figure 2 *a) Ternary diagram shows classification of reservoir sandstones of Sognefjord Formation (adapted from Martin and Lowrey, 1997), crossplots of b) depth versus gamma, c) depth versus resistivity, d) depth versus density and e) depth versus Vp (P-wave velocity) of measured log data of Sognefjord Formation in well 32/4-1 (Alpha structure). The log responses of three reservoir zones are somewhat different which may represent deposition of good quality reservoir sands in a nearshore to shoreface setting which was locally tidally influenced with variable energy.*

Results and Discussion

Overall, Sognefjord Formation penetrated by well 32/4-2 represents a good quality reservoir with some local variations at the upper section (Zone-1 and Zone-2) which contains more shale/clay compared to the lower section (Zone-3). The shale volume varies from 20 to 60% in the upper section (zone-1 and zone-2) compared to 20 to 25% in the lower section (zone-3) (Fig. 3a). In general, the average porosity of the Sognefjord reservoir sandstone is high (~30%) with some local variations of upper and lower sections. The high porosity spikes in the upper part correlate well with high clay content in the section (Figs. 3a-b) whereas the extremely low porosity spikes in the lower section correlate with high resistivity (Fig. 1c), high density (Fig. 1d) and high Vp (Fig. 1e) and interpreted as carbonate stringers.

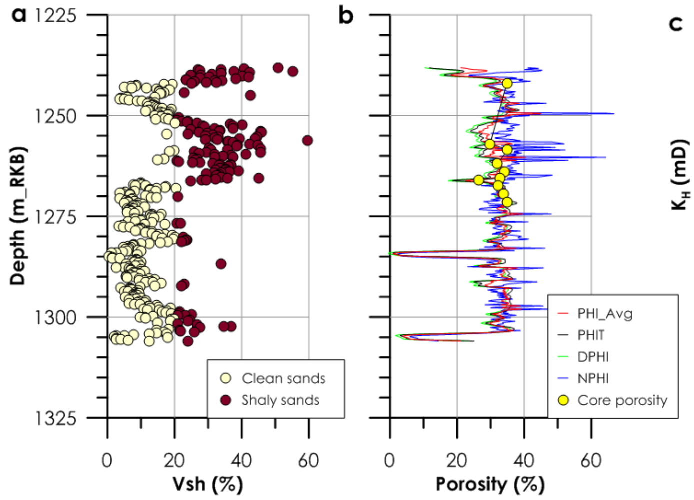

***Figure 3** a) Calculated shale volume (Vsh) of Sognefjord Formation as a function of depth, b) Comparison of estimated (porosities calculated from density and sonic logs) and measured (neutron porosity and lab measured using core) porosities of the reservoir sandstone shows good agreement between different measurements and porosity estimation. PHI_Avg is the average porosity of neutron (NPHI), density (DPHI) and sonic (PHIT) proposities, c) porosity versus horizontal permeability (K_H) plot of 12 selected core samples from Zone-1 (red), Zone-2 (drak brown) and Zone-3 (green). The lab measured porosity and permeability data are adapted from Martin and Lowrey, 1997.*

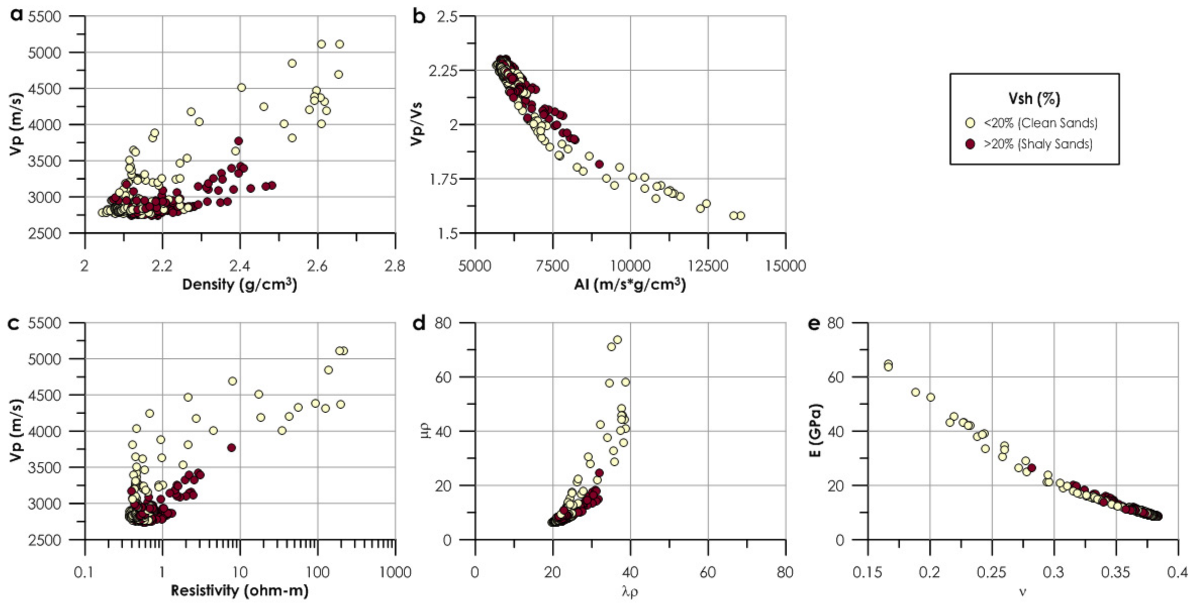

***Figure 4** Crossplots of a) Vp versus Density, b) Vp/Vs ratio versus Acoustic Impedance (AI), c) Vp versus Deep Resistivity, d) LMR (Lamda-Rho versus Mu-Rho) and e) Young's Modulus (E) versus Poisson's Ratio (ν) of Sognefjord Formation. The scattered of acoustic and elastic parameter of Sognefjord Formation may reflect local variability of deposition environment in a nearshore to shoreface setting which may influenced with variable energy conditions. All crossplots color coded by shale volume.*

Porosity and permeability measured in the lab using only a single core plug from Zone-1 (Fig. 3c). However, the sample tested has good porosity and permeability characteristics though it is located within a more argillaceous and/or finer grained section (Fig. 3a). This reservoir Zone-2 exhibits the widest range of reservoir quality, particularly with respect to permeability, seen in any of the zones. The relationship between porosity and permeability in this zone shows a strong positive relationship with rapid increases in permeability associated with relatively small increases in measured porosity. The reservoir Zone-3 has excellent reservoir quality throughout with porosity consistently above 30% and permeability consistently above 4000mD (Fig. 3c). The range of porosity values in Zone-3 is very narrow and hence there is virtually no relationship between measured porosity and permeability. The variations in permeability of Sgnefjord Formation are therefore, interpreted to be controlled by variations in pore connectivity and possibly pore size rather than by absolute volumes of porosity.

Crossplotting density, Vp, resistivity and elastic properties in conjunction with the rock physics templets demonstrates an wide variability of different parameter with the reservoir sandstone that controlled by the presence of shales and carbonate stringers in the formation (Fig. 4). The clean sand intervals show high density, Vp and resistivity (Fig. 4a and c) compared to shale dominated unit. As expected, the sandy units exhibits more brittle (high E, high $\mu\rho$ and low ν) compared to shaly units (Figs. 4d-e). The Vp/Vs versus AI crossplot follows a brine trend line for all data (Fig. 4b) where the shale dominated units show high Vp/Vs ratio and low acoustic impedance compared to sand dominated units.

Conclusions

The Sognefjord Formation is considerably thinner (65m) in well 32/4-1 (Alpha structure) compared to well 32/2-1 (Beta structure) to the east and well 31/6-6 to the west where it reaches thickness 114m and 145m respectively. The section in this well may, therefore, be considerably condensed. With respect to overall reservoir quality then the best reservoir unit is present in the lower section (Zone-3, high porosity, low clay content, high permeability). The consistency of the reservoir quality in zone-3 is attributed to the clean nature of the sandstone. This sandstone unit is virtually uncemented, contains fairly small volumes of clays and is relatively uncompacted. The level of diagenetic maturity achieved by the studied sandstones is very low in terms of both chemical (mineral precipitation, alteration and dissolution) and physical (compactional) changes. This lack of change (preserving high porosity) is considered consistent with the present day shallow burial depth of the sediments (< 1500m) and also suggests that if this depth has been greatly exceeded during the burial history of the reservoir sandstone it was not for any length of time (e.g. Dutton, 1997).

Acknowledgements

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