Triassic Regional Rock Physics Study in the Eastern Barents Sea for Prospectivity Analysis

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Summary

The first block for exploration in the formerly disputed zone between Norway and Russia (PL589) was awarded in 2016 and is located 250 kilometres from the nearest exploration well. The main objectives of the study were to assess the potential prospectivity of the Late Neogene uplifted Triassic targets using rock physics to take into account the impact of the uplift in an attempt to de-risk observed amplitude versus angle (AVA) seismic anomalies identified on pre-stack broadband seismic data at the Triassic level.

The significant uplift during the Late Neogene in the Barents Sea area did not allow for a simple regional rock physics model to be established in order to interpret these anomalies. To address this challenge a regional rock physics model based on 13 wells was built taking into account the uplift to model the expected response at the Triassic reservoir level. This study indicates that porosity might be preserved around the PL589 area in the Triassic and helped classify anomalous channelised sandstones using relative acoustic impedance and relative Vp/Vs properties as potentially hydrocarbon filled.

Introduction

Large areas of the Barents Sea, like the formally disputed zone between Norway and Russia in the Eastern Barents, are still undrilled. An exploration license was recently awarded over the Haapet Dome (PL859), with a prime interest in shallow Jurassic reservoirs (Reiser et al, 2016). However, it is also important to try to understand the prospectivity of deeper targets like the Triassic. A post-glacial rebound, which created uplift locally reaching 3,000 metres during the Late Neogene, complicates the geological history and makes the prospectivity assessment in the Triassic difficult (Fjeldskaar et al, 2013). In this study a regional rock physics model accounting for the uplift was reconstructed to evaluate the prospectivity potential of Triassic reservoirs. A pre-stack inversion using 3D MultiClient dual-sensor broadband seismic data acquired in 2014 and 2015 in and south of PL859 helped in validating the rock physics model and understanding the potential prospectivity. The nomenclature used in this abstract for depth is TVDml or true vertical depth below mudline (seabed).

Geological Background

The Kobbe and Snadd sandstones are the main Triassic reservoirs in the Barents Sea (Figure 1) and were deposited from south-east to west-north-west during the Mid Triassic to Late Triassic. The sands originated from the erosion of the newly formed Ural Mountains and deposited in a coastal environment alternating between shallow shoreface to deltaic in the Eastern Barents Sea (Riis et al, 2008). A maximum marine transgression during the Late Jurassic and Early Cretaceous flooded the whole area forming regional markers such as the Hekkingen organic rich shale. The Cenozoic and most of the Cretaceous units have been eroded in a major uplift after the last glaciation during the Late Neogene (Basov et al. 2009).

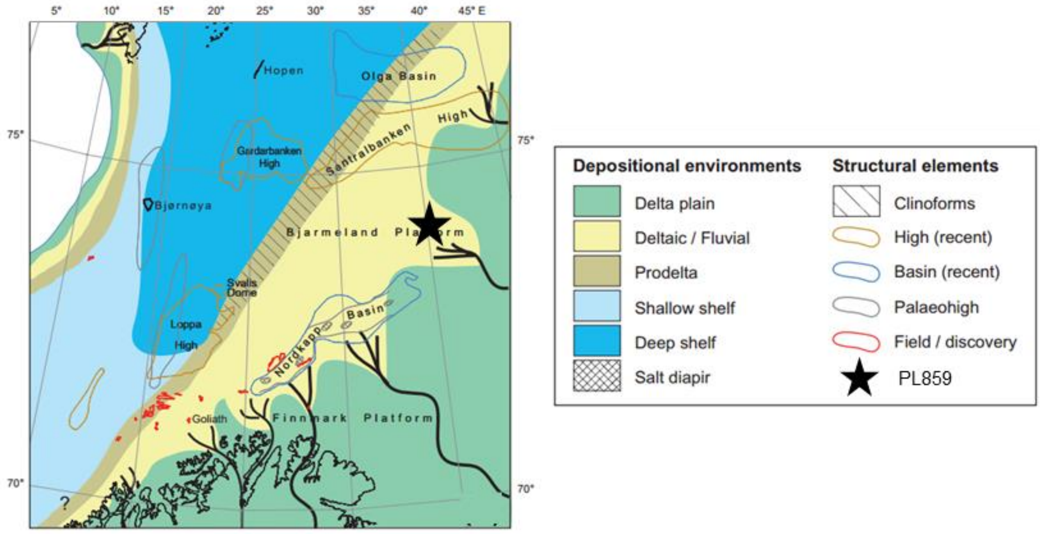

Figure 1 *Mid Triassic paleo-geography of the Barents Sea (Riis et al, 2008).*

Regional Rock Physics Methodology

It is possible to estimate and map the amount of uplift and erosion across the Barents Sea (Figure 2.a.) using various techniques such as the Opal A/CT boundary (sometimes visible on seismic data), geochemical information from well data such as the vitrinite reflectance index or the shale compaction trend from sonic logs compared to seismic velocities (Henriksen et al, 2011). These geophysical and geochemical markers record the pressure and temperature reached at the maximum paleo-burial depth. Most of the uplift and erosion is believed to have taken place over the last 3 million years (Fjeldskaar et al, 2013) and, based on this fast and very recent uplift, it is assumed that no major low pressure and low temperature metamorphism has occurred since and thus the rock properties remained the same as at the deepest burial depth.

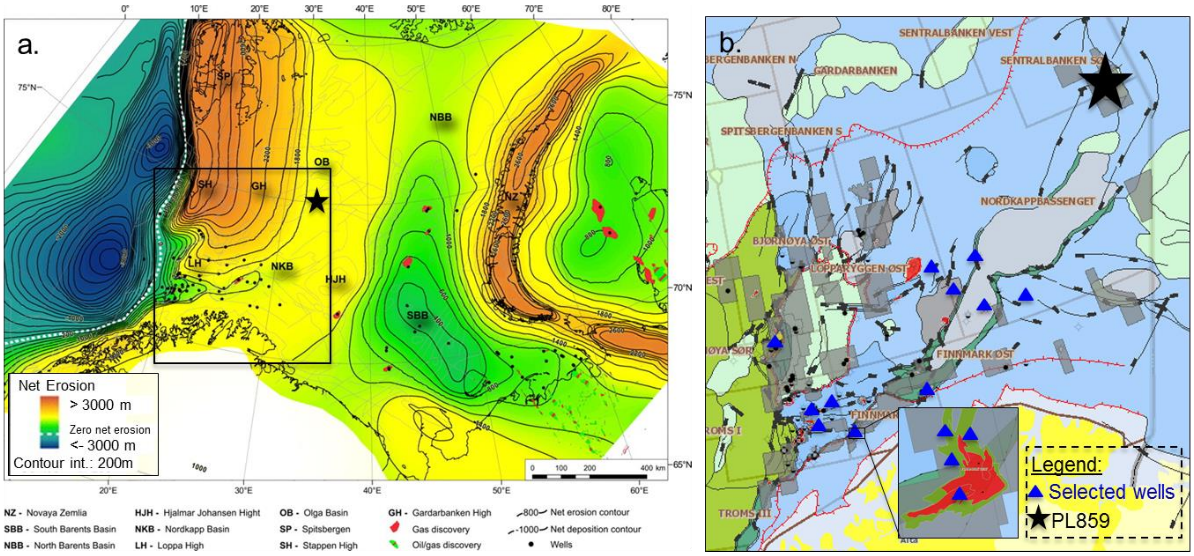

Figure 2 *a. Regional map illustrating the estimated net erosion for the Greater Barents Sea from Henriksen et al, 2011. b. A selection of 13 wells across the Barents Sea to cover Triassic reservoirs in various uplift regimes.*

The variable uplifts across the area make a regional reservoir characterisation approach very challenging. Two time equivalent sandstones could have been buried and may lie today at depths totally unrelated to their maximum burial depth. To compare the physical properties of these two sandstones today, a simple workflow based on Henriksen's work was created. Using an uplift and erosion map (Henrinksen et al, 2011), each well was corrected for the amount of uplift estimated to have occurred locally (Figure 3). By doing so, a paleo-regional rock physics model using an end-member picking technique was generated using 13 regional wells selected across the Barents Sea (Figure 2.b.). This method consists of picking in each well, the cleanest members of sandstones and shale at various depths in order to identify depth dependant trends in the rock physics properties (Figure 4). All hydrocarbon bearing reservoirs were previously fluid substituted using Gassmann's equations with brine properties.

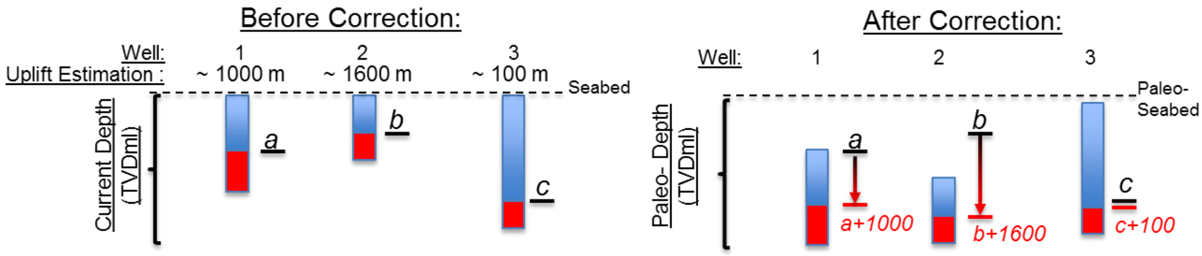

Figure 3 *Correction for uplift is applied to each well using Henriksen's uplift and erosion map. The depth axis shows thereafter the paleo-depth before uplift or maximum burial depth.*

Regional Rock Physics Results

P-velocity, S-velocity, porosity and density paleo-trends prior to the Late Neogene were generated using end member picking. Figure 4 shows that porosity greater than 10% can be expected down to 4,000 metres paleo-depth for the Triassic. Today, in the area of interest, the interpreted Triassic reservoirs reside at 2,300 metres below seabed. The level of uplift affecting this zone is estimated at 1,500 metres according to Henriksen's work (Figure 2.a.). A simple calculation suggests that these Triassic reservoirs were buried at 3,800 metres below paleo-seabed before the Late Neogene. According to these results, an average porosity of 12% could be expected in the Triassic in the PL859 area.

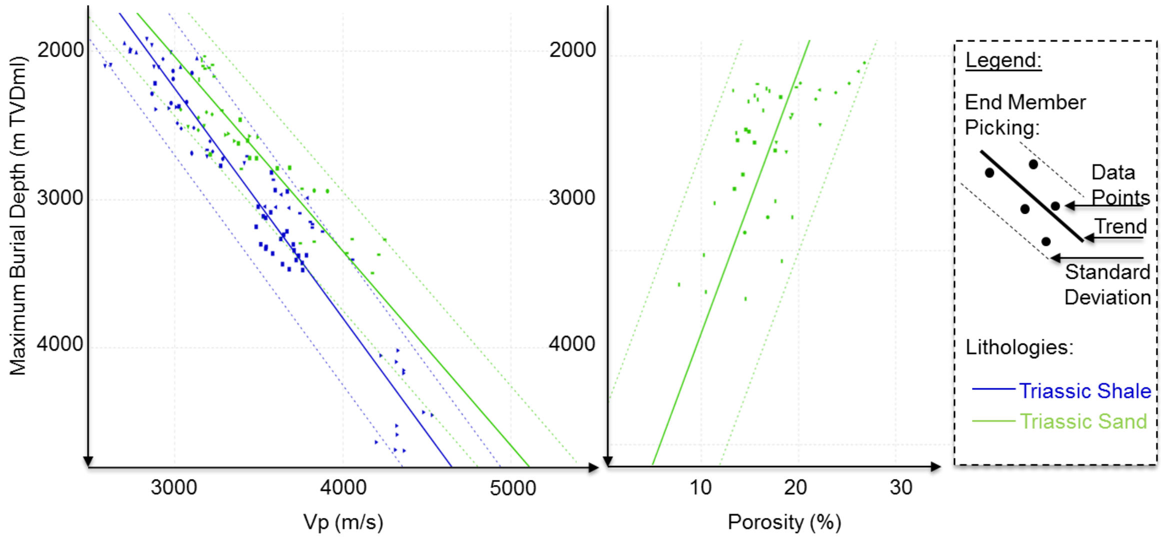

Figure 4 *P-velocity versus depth trend for Triassic shale and sandstones derived using the end member picking technique at the maximum depth of burial prior late Neogene for brine reservoirs.*

Taking into account the uncertainties of the picking of end members and the depth trend, stochastic forward models using Monte Carlo simulations were generated in order to estimate the elastic properties, Acoustic Impedance (Ip) and Velocity Ratio (Vp/Vs) responses, expected in the depth interval of interest for Triassic targets (Figure 5). According to this model, Triassic sandstone reservoirs are expected to be discriminated from the shale due to a lower Vp/Vs response which could be amplified by the presence of hydrocarbon (gas or oil). Hydrocarbon filled reservoirs are also believed to "soften" the Ip response compared to the shale, while brine filled reservoirs cannot be discriminated from the shale in the Ip domain.

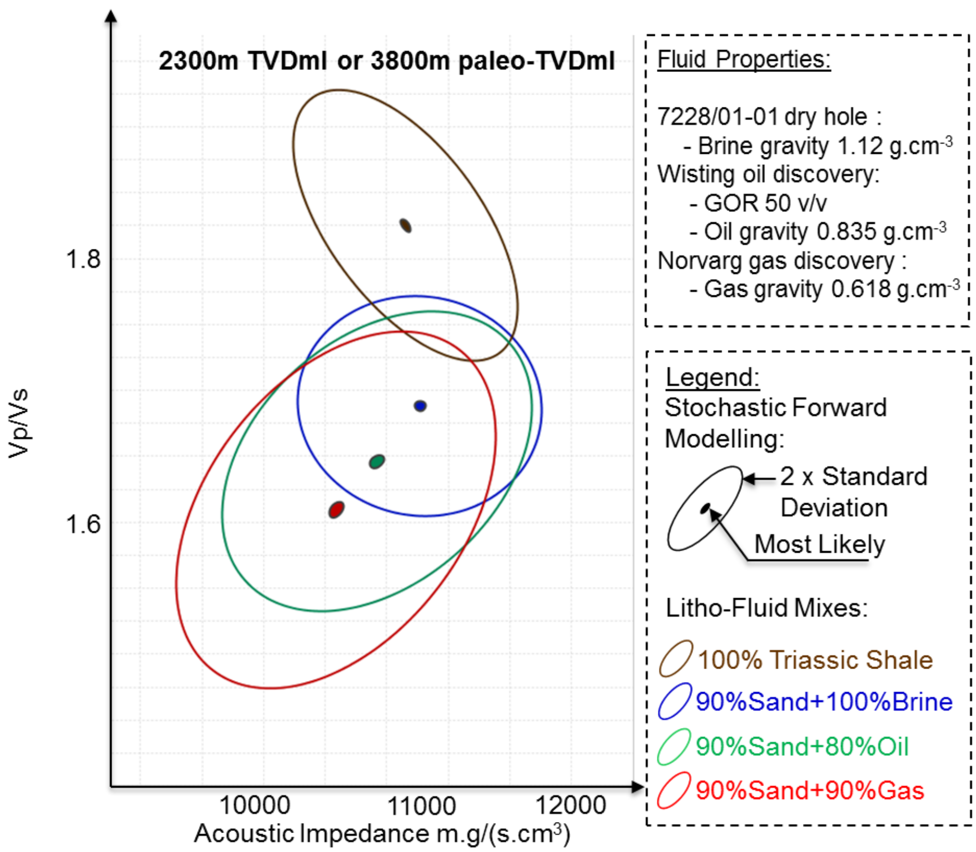

Figure 5 *Stochastic forward modelling generated at target depth considering the level of uplift.*

Pre-Stack Inversion Results

Relative Ip and Vp/Vs were estimated using a seismic inversion engine and three angle stacks (7-18 degrees, 18-28 degrees and 28-36 degrees) generated from pre-stack depth migration with compensation for amplitude loss and phase distortion (Valenciano et al, 2013) acquired using dual-sensor streamer. Figure 6 shows a multi-kilometre wide meandering channel with a negative relative Vp/Vs response throughout. Locally a negative relative Ip response is collocated within the negative relative Vp/Vs response. According to the rock physics, the negative relative Ip response can be explained by the presence of hydrocarbon filled reservoirs trapped against sealing faults.

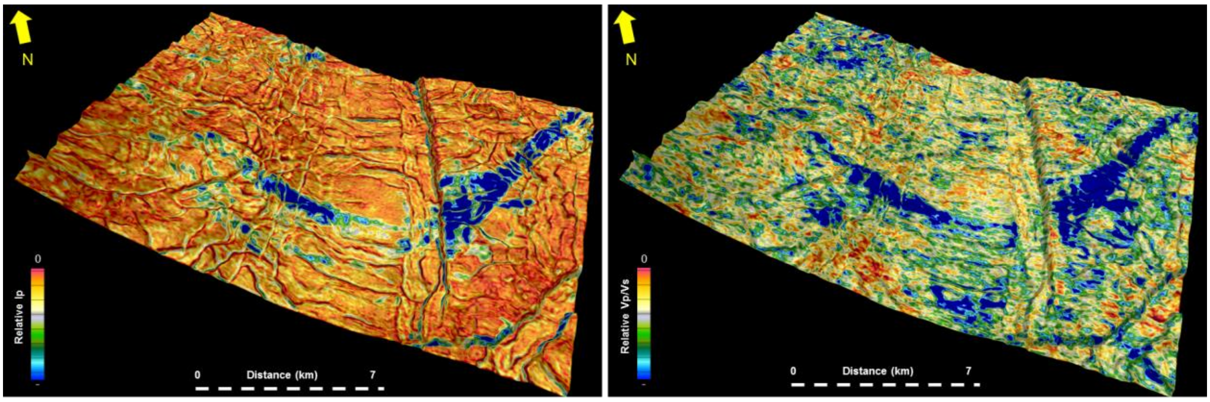

Figure 6: *Minimum relative acoustic impedance (left) and minimum relative Vp/Vs (right) extracted along an interpreted horizon near top Kobbe.*

Conclusion

A regional rock physics approach in the Eastern Barents Sea suggests interesting levels of prospectivity for the Triassic in, around and south of the PL859 area. Relative Ip and Vp/Vs attributes estimated through a pre-stack seismic inversion and combined with the established rock physics model, should provide the necessary seismically derived information to de-risk the Triassic targets. The first exploration well is planned to be drilled during the summer of 2017 in the PL859 area but it is not known whether it will target the Triassic.

Acknowledgements

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References

Fjeldskaar, W. & Amantov, A. [2013] Neogene Uplift of The Barents Sea. FORCE seminar, Tectonor/UiS, Stavanger, Norway.

Henriksen, E., Bjørnseth, H. M., Hals, K. T., Heide, T., Kiryukhina, T., Kløvjan, O. S., Larssen, G. B., Ryseth, A. E., Rønning, K., Sollid, K. & Stoupakova, A. [2011] Uplift and erosion of the greater Barents Sea: impact on prospectivity and petroleum systems. Geological Society, London.

Reiser, C. & Bird, T. [2016] Advances in broadband quantitative interpretation. SEG Annual Meeting Dallas, Extended Abstract.

Riis, F., Lundschien, B.A., Høy, T., Mørk, A. & Mørk, M.B.E. [2008] Evolution of the Triassic shelf in the northern Barents Sea region. Polar Research, 27, 298-317.

Valenciano, A.A. & N. Chemingui N. [2013] Tomographic Q Estimation for Viscoacoustic Imaging. EAGE Annual Meeting London, Extended Abstract.