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Combined Rock-Physical Modelling and Seismic Inversion Techniques for Characterisation of Stacked Sandstone Reservoir

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SUMMARY

The objective of the study is to characterise the Triassic massive stacked sandstone deposits of the Main Buntsandstein Subgroup at Block Q16 located in the West Netherlands Basin. The characterisation was carried out through combining rock-physics modelling and seismic inversion techniques. The application of inversion on time-converted PSDM stack results in better seismic impedance resolution due to better well-seismic match performance. The results show that even though the Bunter reservoir consists of lithologically uniform massive stacked sandstones, the obtained rock property volumes allow distinguishing two zones within the target unit. The upper zone - Hardegsen and Detfurth Formations - exhibits on average lower acoustic impedance, shear impedance and bulk density values compared to the lower zone - the Volpriehausen Formation. These differences are essentially attributed to changes in porosity. Larger porosities make these rock properties decrease. Moreover, it is believed that locally the entire Bunter reservoir is gas-bearing, but the Volpriehausen sandstones are tighter. Vp/Vs ratio and Poisson's ratio are good gas-fluid indicators. Both decrease for Bunter reservoirs compared to shales of the Solling and Rogenstein Formations. Furthermore, the rock property volumes allowed improved mapping of top and base of the Bunter reservoir compared to the original seismic reflectivity volume.

Introduction

The objective of the study is to characterise the Triassic sandstone deposits of the Main Buntsandstein Subgroup at Block Q16 located in the West Netherlands Basin. The characterisation of this deposit was carried out through seismic inversion techniques. After calibration, the characterisation is made by analysing rock properties obtained from seismic inversion aiming to understand their variations with depth, lithology, porosity and fluid content.

The Main Buntsandstein Subgroup consists of Early Triassic arkosic sandstones and clayey siltstones of approximately 200 meters thickness deposited under fluvial and eolian sedimentary environments. It comprises the Volpriehausen, Detfurth and Hardegsen Formations. Porosities vary from less than 6 to almost 20%, gas saturations range from 30 to 80%. Volpriehausen sandstones can be tightly cemented by dolomite, reducing the porosity and therefore the quality of the reservoir (Geluk at al., 1996). In this study the Main Buntsandstein Subgroup is referred to as the Bunter reservoir.

Methodology

Seismic inversion techniques were employed in order to characterise the Bunter reservoir, at Q16-block, offshore the Netherlands, about 25 km W of The Hague. Figure 1 shows a flow chart of this study and its location. 3D Seismic data dating from 2013 is used as input in the seismic inversion. A 3D seismic cube of 256 km^2 was used in this study. The seismic data was available as pre-stack time- and depth-migrated (PSTM and PSDM) stacks and as CDP NMO-corrected gathers. The other input for the seismic inversion comprised well-logs. GR, P-wave transit times, bulk density, neutron porosity and depth resistivity logs were collected, organised, processed and interpreted. On the other hand, S-wave transit times were estimated through a Xu-White Model (Xu and White, 1995;1996).

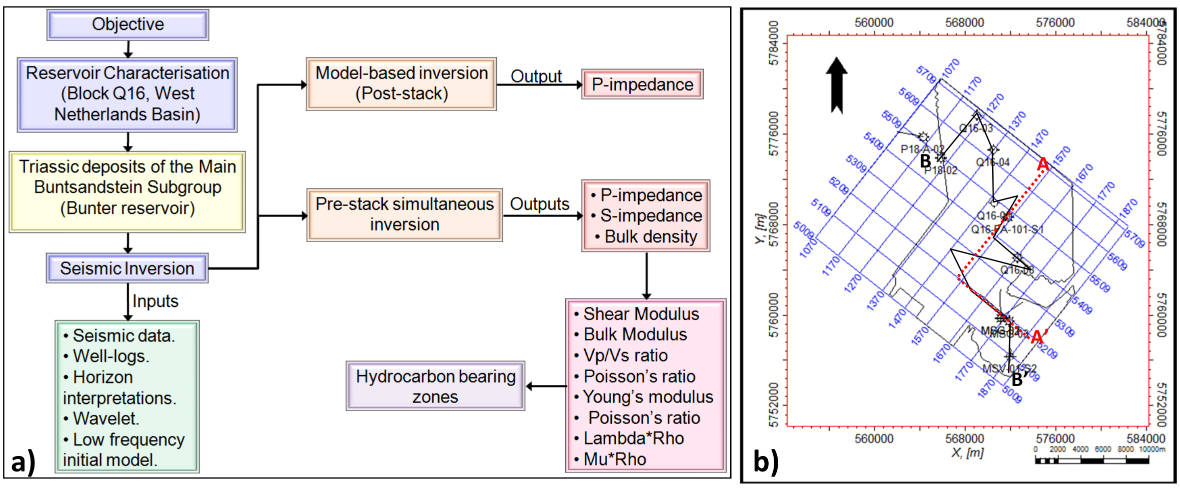

Figure 1 a) Flow Chart and b) Location of the Study Area.

Two types of seismic inversion were carried out, a post-stack model-based seismic inversion and a pre-stack simultaneous seismic inversion, both using the Hampson & Russell software. In this study, the model-based inversion was hard constraint, which means that the change in impedance is limited. This change is expressed as a percentage of the well-log average acoustic impedances. To study the influence of depth-processing in the seismic inversion, the post-stack inversion was applied to PSTM and time-converted PSDM stacks.

The pre-stack simultaneous inversion employs the gathers data in order to generate acoustic impedance, shear impedance and bulk density models. Moreover, pre-stack simultaneous inversion takes into consideration the offsets or angles of reflections and also use low frequency models of shear impedance and bulk density. In this study, the final outputs are P-impedance, S-impedance and bulk density volumes.

The low frequency models were built using well-logs, RMS velocities and interpreted horizons. A high cut filter was applied on the models. Obviously, these models contain frequencies below 10 Hz, which are missing from the seismic data. Synthetic seismograms were generated and correlated with the 3D data. Subsequently several horizons were interpreted. In the construction of the models these horizons guide the lateral interpolation of the model between wells. They constitute essential structural and stratigraphic constraints to the model, in this structurally complex area, where a prominent horsts and graben system is present below the Base Cretaceous Unconformity. A wavelet was extracted using wells and seismic data, followed by some manual editing. Its bandwidth spans from approximately 10 to 70 Hz.

Rock properties were calculated from the obtained acoustic impedance (Zp), shear impedance (Zs) and bulk density (ρ_b) volumes. These properties were: P-wave velocity (Vp), S-wave velocity (Vs), Vp/Vs ratio, Poisson's ratio (υ), shear modulus or second Lamé parameter (μ), Bulk modulus or incompressibility (K), Young's modulus (E), first Lamé parameter (λ), $\lambda*\rho$ and $\mu*\rho$. Similar estimations were done from well-log data. Several crossplots were created in other to analyse the behaviour of these rock properties at the Bunter reservoir.

Results

The application of post-stack inversion on time-converted PSDM stack shows a better performance in terms of resolution and S/N ratio. This suggests that the time-converted PSDM stack preserves the structural and spectral contents of the signal which lead to better well-seismic match and finally improve the inversion result (Figure 2).

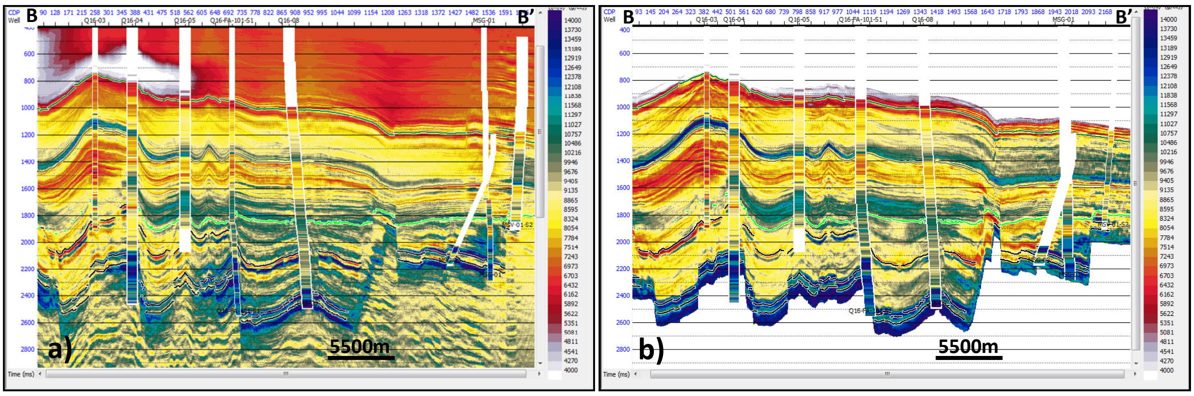

Figure 2 *Model-based inversion applied on PSTM and time-converted PSDM stacks: a) Acoustic impedance (Zp) from PSTM, b) the same impedance from PSDM. The arbitrary line location is shown in Figure 1 (black solid line).*

Figure 3 shows a composite line of Zp, Zs and ρ_b resulted from the pre-stack simultaneous inversion. The line passes through two wells. Well-logs of Zp, Zs and ρ_b have been inserted. It is observed that the inversion results honour the well data. The top of the Bunter reservoir is well recognised by the suddenly decreasing of Zp, Zs and ρ_b. Two zones can be distinguished within the Bunter reservoir, one shallower zone with lower Zp, Zs and ρ_b and a deeper area with higher Zp, Zs and ρ_b. It is interpreted that Hardegsen and Detfurth Formations belong to the upper zone and the Volpriehausen Formation is the lower part.

The rock bulk modulus is mainly dependent on the pore fluid properties. Conversely, the rock shear modulus is hardly affected by fluids, since fluids do not support shear. Therefore, when a liquid is replaced by compressible free gas in the pore space, the rock P-wave velocity will decrease considerably, meanwhile the rock S-wave velocity will be slightly increased because of the decreasing bulk rock density. As a result, the Vp/Vs ratio is considered to be a good indicator of free gas in the pore space (Justiniano, 2014).

Figure 4 displays a composite line through two wells, showing Poisson's ratio, Young's modulus and Vp/Vs ratio. The Vp/Vs ratio varies from approximately 1.5 to 1.8, Poisson's ratio goes from about 0.1 to 0.28 and Young's modulus changes from approximately 25 to 65 GPa. It is noticed that the base of the Bunter reservoir is better recognised in properties like Vp/Vs ratio and Poisson's ratio because the Volpriehausen Formation has lower values than the Rogenstein Member. Both the Poisson's ratio and Vp/Vs ratio exhibit low values at Bunter reservoir levels. The Young's modulus is lower in the upper part of the reservoir and higher in the Volpriehausen Formation.

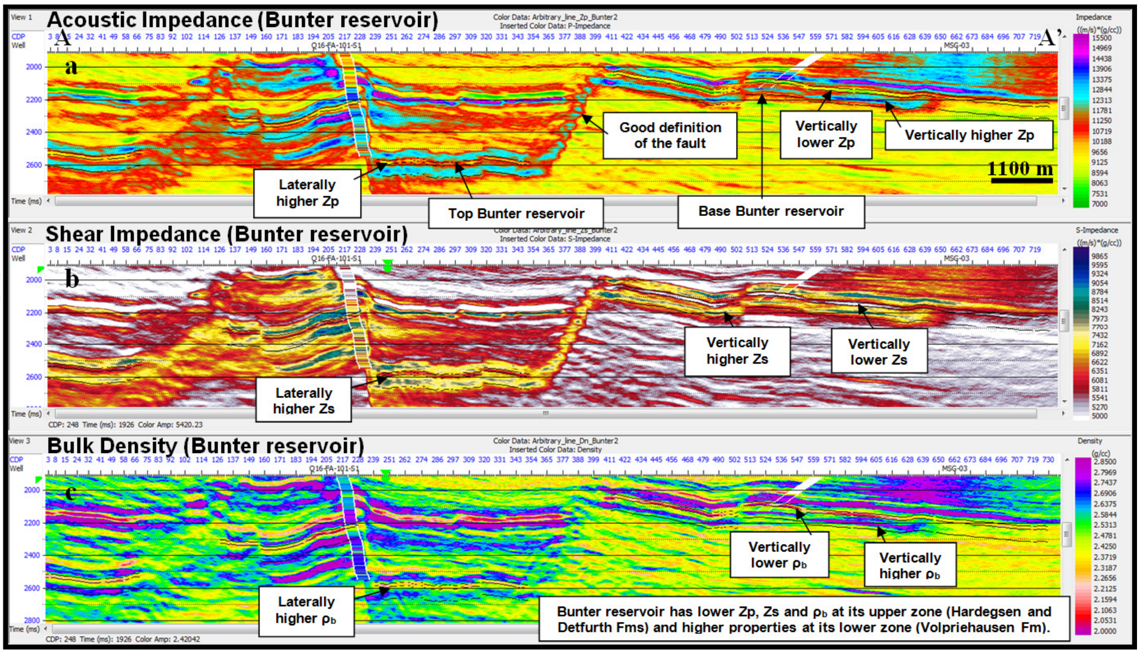

Figure 3 *Pre-stack simultaneous inversion results at Bunter reservoir interval. Composite line: a) Acoustic impedance (Zp), b) Shear impedance (Zs) and c) Bulk density (ρ_b). The arbitrary line A-A' location is shown in Figure 1 (red dashed line).*

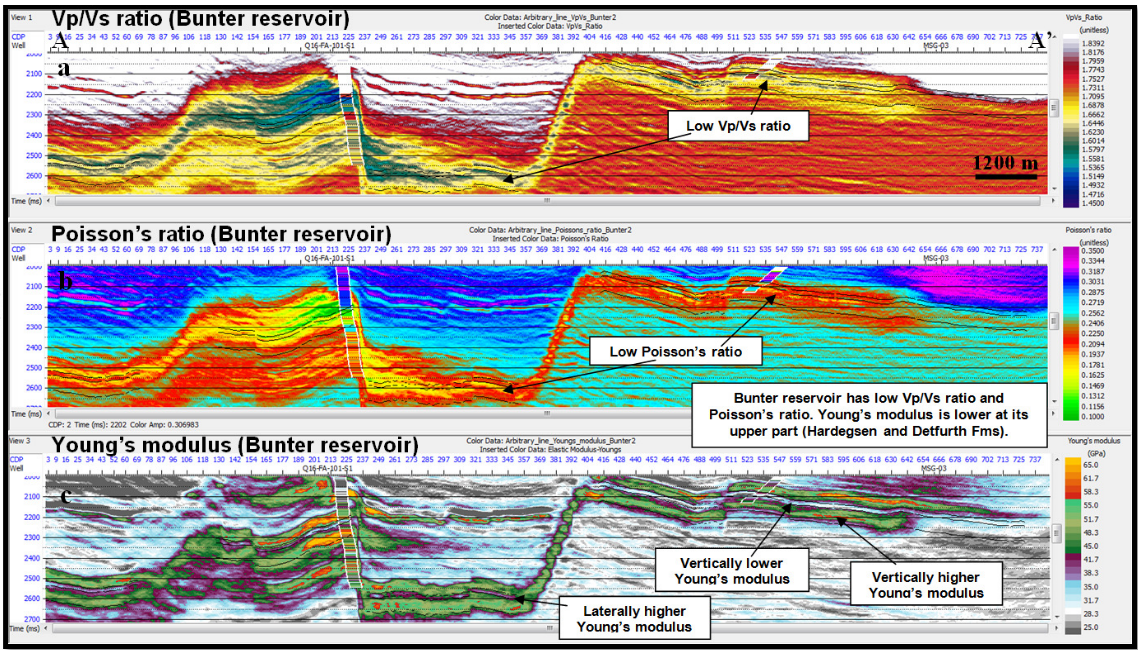

Figure 4 *Rock properties estimated from Zp, Zs and ρ_b at Bunter reservoir interval. Composite line: a) Vp/Vs ratio, b) Poisson's ratio and c) Young's modulus. The arbitrary line A-A' location is shown in Figure 1 (red dashed line).*

Several rock property maps of the Bunter reservoir were generated. Figure 5 illustrates a Vp/Vs ratio map of the Bunter reservoir interval showing the possible areas that could be gas-bearing. These zones present low Vp/Vs ratio.

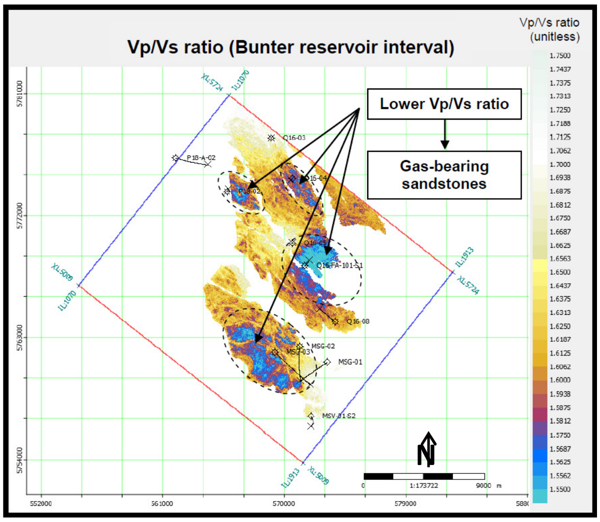

Figure 5 *Vp/Vs ratio map at Bunter reservoir interval.*

Conclusions

Even though the Bunter reservoir consists of lithologically uniform massive stacked sandstones, the obtained rock property volumes allow distinguishing two zones within the target unit. The upper zone - Hardegsen and Detfurth Formations - exhibits on average lower acoustic impedance, shear impedance and bulk density values compared to the lower zone - the Volpriehausen Formation. These differences are essentially attributed to changes in porosity. Larger porosities make these rock properties decrease. Moreover, it is believed that locally the entire Bunter reservoir is gas-bearing, but the Volpriehausen sandstones are tighter. Vp/Vs ratio and Poisson’s ratio are good gas-fluid indicators. Both decreases at the Bunter reservoir in comparison with the bounded shales Solling and Rogenstein Formations. Furthermore, these rock property volumes allowed mapping the top and base of the Bunter reservoir much better than in the original seismic reflectivity volume.

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