RP24

Combined Rock-physical Modelling and Seismic Inversion Techniques for Characterisation of the Posidonia Shale Formation

A. Justiniano* (SGS Horizon BV), M. Jaya (SGS Horizon BV), G. Diephuis (Delft University of Technology) & R. Veenhof (Oranje-Nassau Energie BV)

SUMMARY

The objective of this study is to characterise the Jurassic Posidonia Shale Formation at Block Q16 located in the West Netherlands Basin. The characterisation was carried out through combining rock-physics modelling and seismic inversion techniques. The results show that the Posidonia Shale Formation can be followed easily laterally from the output rock property volumes, in particularly the acoustic impedance volume. This is an advantage when horizontal drilling needs to be performed. A brittleness index map was built from the Poisson's ratio and Young's modulus properties. A more brittle area was observed in the South of the mapped Posidonia Shale, which implicates that this area is easier to be fractured.

Introduction

The objective of this study is to characterise the Jurassic Posidonia Shale Formation at Block Q16 located in the West Netherlands Basin. The characterisation of this deposit was carried out through seismic inversion techniques. The main purpose of this characterisation is to analyse the rock properties obtained from seismic inversion in order to understand their variations related to depth, lithology, porosity and fluid content, and calibrate these with known well information.

The Posidonia Shale Formation is a Toarcian bituminous claystone deposited under anoxic conditions during a period of high sea level. It is a type II kerogen source rock with an average TOC content of approximately 5-7% and an average thickness of 30 meters. This Formation is considered the main source rock for hydrocarbon generation in the western zone of the West Netherlands Basin (van Bergen, 2013). According to these characteristics, Posidonia Shale Formation can be classified as an unconventional reservoir. These types of reservoirs present a very low permeability, typically less than 1mD. Structural or stratigraphic traps are not needed for producible hydrocarbon accumulations; hence they may be laterally extensive. Hydraulic fracturing, also known as fracking, is a method employed for producing hydrocarbons from these unconventional deposits. The rock is fractured to create pathways through which gas or oil can flow (Speight, 2013 and Treadgold *et al.* 2010).

Oil and gas shales can be heterogeneous, in the sense of mineral composition such as clay minerals, quartz, carbonates, pyrites and others. Areas of shales with higher content of brittle minerals like quartz and carbonates are easier to fracture than zones with higher percentage of clay, where the behaviour of the rock could be more plastic or ductile (Verma *et al.* 2012). Therefore, sweet spots with large amount of brittle minerals could be identified in order to optimize the hydrocarbon recovery. A rock that is considered brittle is more susceptible to be fractured. The brittleness index is a parameter that allows the quantification of the rock brittleness. This can be estimated through the rock properties of Poisson's ratio and Young's modulus that can be derived using P-wave velocities, S-wave velocities and bulk densities (Perez *et al.*, 2013).

Methodology

Seismic inversion techniques were employed in order to characterise the Posidonia Shale Formation, at Q16-block, offshore the Netherlands, about 25 km W of the Hague. Figure 1 shows a flow chart of this study and an interpreted structural map of the base of the Posidonia Shale Formation at the location of interest. A 3D seismic volume of 256 km² re-processed in 2013 was used as input in the seismic inversion. The seismic data was available as CDP NMO-corrected gathers that were previously pre-stack time migrated. Other input for the seismic inversion comprised well-logs. Gamma ray, P-wave transit times, bulk density, neutron porosity and depth resistivity logs were collected, organised, processed and interpreted. On the other hand, S-wave velocities were estimated through a Xu-White Model (Xu and White, 1995; 1996).

Figure 1 a) Flow Chart. b) Interpreted structural map of the base of the Posidonia Shale Formation.

A pre-stack simultaneous seismic inversion was carried out using the software Hampson & Russell. This inversion employs the CDP gathers in order to generate acoustic impedance, shear impedance and bulk density volumes. The pre-stack simultaneous inversion takes into consideration the offsets or angles of reflection and, it also makes use of low frequency models of acoustic impedance, shear impedance and bulk density.

Synthetic seismograms were generated and correlated with the 3D data. Subsequently, several horizons were interpreted. The low frequency models were built using well-logs, RMS velocities and interpreted horizons. In the construction of the models, these horizons guide the lateral interpolation 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 estimated from the obtained acoustic impedance (Z_p), shear impedance (Z_s) and bulk density (ρ_b) volumes. These properties were: P-wave velocity (V_p), S-wave velocity (V_s), V_p/V_s ratio, Poisson's ratio (ν), shear modulus or second Lamé parameter (μ), Bulk modulus or incompressibility (K), Young's modulus (E), first Lamé parameter (λ), $\lambda \cdot \rho$ and $\mu \cdot \rho$. Similar estimations were done from well-log data. Several crossplots were created in order to analyse the behaviour of these rock properties at Posidonia Shale Formation. A brittleness index (BI) was estimated using the well-logs and the volumes of Poisson's ratio and Young's modulus.

Results

Shear impedance was plotted against acoustic impedance and Poisson's ratio was plotted against Young's modulus at Posidonia Shale interval (Figure 2). The volume of shale (V_{sh}) decreases at larger values of Young's modulus and lower values of Poisson's ratio. Young's modulus describes the resistance of a material to be deformed when it is submitted to compressive or tensile forces. Moreover, Young's modulus is defined as the ration of the shear stress to the shear strain (Mavko *et al.*, 2009). Therefore, it is consistent to observe that deposits with lower V_{sh} have higher Young's modulus. Regarding the Poisson's ratio, this is defined as the lateral strain divided by longitudinal strain. Deposits with higher V_{sh} have larger Poisson's ratio because they present more anisotropy due to the large clay content than in areas with an increased amount of quartz and/or carbonates mineral. The ratio between lateral and longitudinal strains is smaller in brittle mineral than in soft ones. Furthermore, the relationship between Poisson's ratio and Young's modulus is important in order to find areas of higher brittleness and therefore easily to fracture. The brittleness increases in areas where the Poisson's ratio decreases and the Young's modulus increases (Justiniano, 2014).

Figure 2 Well-log crossplots coloured with V_{sh} at Posidonia Shale interval. a) Shear impedance versus acoustic impedance. b) Poisson's ratio versus Young's modulus.

Figure 3 shows an arbitrary line of the seismic compared with the Z_p and Z_s resulted from the pre-stack simultaneous inversion. The line passes through five wells at Posidonia Shale Formation interval. The location of the line can be observed in the Figure 1. The well-logs are original Z_p and Z_s represented by the rectangle boxes. It is observed that the inversion results honour the well data,

meaning that Z_p and Z_s decrease at Posidonia Shale interval compared to the Formations above and below. Laterally, it is noticed that the values of these properties increase from North to South within the Posidonia Shale. Furthermore, Poisson's ratio, Young's modulus and brittleness index are also displayed. Laterally, the Young's modulus increases to the south. Lower Poisson's ratio is observed at the areas surrounding the well Q16-05. Higher brittleness index is distinguished at South within Posidonia Shale interval.

Figure 3 Pre-stack simultaneous inversion results at Posidonia Shale interval. Arbitrary line: a) Seismic, b) Acoustic impedance (Z_p), c) Shear impedance (Z_s), d) Poisson's ratio, e) Young's modulus and f) Brittleness index.

Several rock property maps of Posidonia Shale Formation were generated (Figure 4). The Poisson's ratio varies from approximately 0.24 to 0.33, decreasing to the west. The Young's modulus varies from 10 to 35 GPa, being lower at the north and higher at the east. A brittleness index was estimated using the Poisson's ratio and the Young's modulus (Perez *et al.*, 2013). The estimated brittleness index varies from 0.4 to 1, being more brittle 1 and less brittle 0. As a result, higher brittleness, and therefore more frackable areas are distinguished at South within Posidonia Shale interval. On the other hand, lower brittleness or more ductile zones are observed at the North. Lower frackable zones are located at the north close to the wells Q16-03 and Q16-04 which have more clay minerals. Higher frackable areas are situated at the south nearby the well Q16-FA-101-S1, where the Posidonia Shale Formation possess more brittle minerals like quartz or carbonates that are easily to fracture than ductile ones such as clay.

Figure 4 Rock property maps at Posidonia Shale Formation interval. a) Poisson's ratio, b) Young's modulus and c) Brittleness index.

Conclusions

The Posidonia Shale Formation can be followed easily laterally from the output rock property volumes, in particularly the acoustic impedance volume. This is an advantage when horizontal drilling needs to be performed. A brittleness index map was built from the Poisson's ratio and Young's modulus properties. A more brittle area was observed in the South of the mapped Posidonia Shale, which implicates that this area is easier to be fractured.

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