PS Characterization of Seal Potential and Distribution Using Pre-Stack Seismic Inversion: A Field Case Study of Onshore Abu Dhabi*

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Abstract

The outputs of seismic inversion are broadly used to characterize different lithofacies with variant rock properties and to reduce the uncertainties of target reservoirs. The P-wave impedance provides the initial basis of acoustic properties from post-stack seismic data and S-wave impedance provides additional elastic properties from pre-stack seismic data.

Regional indications, such as mudlogging hydrocarbon shows, high oil saturation log, high porosity log values and production test results, have shown high prospectivity of the wide-spread shallow-water Mauddud carbonate reservoir. However, characterizing the efficiency and distribution of seal for the Mauddud reservoir is a challenge. The main objective of this study is to develop a workflow utilizing advanced geophysical techniques including rock physics analysis and seismic inversion, to understand the potential and distribution of seal above the target reservoir.

The overlying Shilaif Formation in the study area was deposited in an intrashelf basin and three zones are identified: S1 (lower part), S2 (middle part), and S3 (upper part). The bitumen-rich zone in S1 of the Lower Shilaif shows sealing potential through well log analysis and it may act as a satisfactory seal for the underlying reservoir. In an oil-bearing source rock play, total organic carbon (TOC) is a mixture of kerogen and liquid hydrocarbon. In this context, bitumen is considered a viscous, soluble hydrocarbon that is an early product of kerogen maturation. Due to its high viscosity, bitumen is less likely to migrate from the kerogen-hosted pore system and is often left behind as a residue after light oil expulsion. The well logs have shown a good indication of the existence of non-movable fluids by the large separation between the porosity from neutron density (PHIT_ND) and the porosity from nuclear magnetic resonance measurements (TCMR). The core analysis also confirmed that the non-movable fluids are with high content of bitumen. Three lithofacies can be identified from well logs: (1) Clean mudstone characterized with inorganic porosity and low total organic content (TOC), (2) Mudstone with porosity partly filled with elevated TOC, and (3) Bitumen-rich mudstone. Seismic elastic property analysis (P-impedance and velocity ratio Vp/Vs) with reservoir properties (TOC and

separation of PHIT_ND and nuclear magnetic resonance measurements) provides valuable insights to the characterization of the target seal. The clean mudstone with inorganic porosity and low TOC is characterized with high P-impedance, while the mudstone filled with movable oil is characterized with low Vp/Vs and low P-impedance, and the target bitumen-rich mudstone is characterized with high Vp/Vs and low P-impedance. Pre-stack simultaneous seismic inversion and Bayesian-based lithofacies classification were carried out to predict the distribution of target seal in study area. The results show that there is a distribution of relative low P-impedance values in the northeastern and southern parts of study area. However, high Vp/Vs values are only present in the northeastern part of the field. The target seal in S1 unit of Shilaif Formation with high TOC and non-moveable bitumen at an early maturity is most probably present in the northeast part of the study area, consistent with well logs correlation results and present-day vitrinite reflectance map.

For the first time, the integration of rock properties and seismic inversion results to predict the potential and distribution of bitumen-rich seal in S1 unit of Shilaif Formation is addressed in this study. The results obtained are valuable information to further rock physics modeling and well placement.

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1. Introduction

The Mauddud Formation is a wide-spread shallow-water carbonate in Arabian Gulf. Regional indications have shown high prospectivity of Mauddud reservoir in study area. However, characterizing the potential and distribution of seal for Mauddud is a challenge. The overlying Shilaif Formation of study area is located in an intrashelf basin (Figure 1). The prospective sealing potential of the bitumen-rich zone is in S1 of Lower Shilaif (Figure 2), which may act as a satisfactory seal for underlying reservoir (Figure 3). For the first time, the integration of rock properties and seismic inversion results to predict the potential and distribution of seal is addressed in this study.

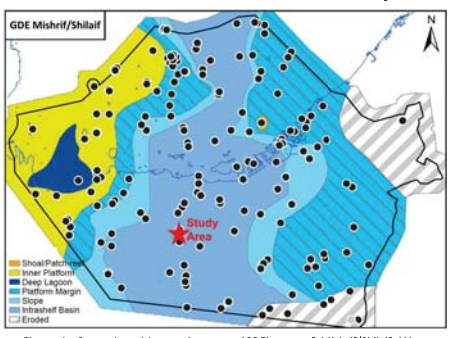

Figure 1: Gross deposition environment (GDE) map of Mishrif/Shilaif (Abu Dhabi petroleum system portfolio study, 2018).

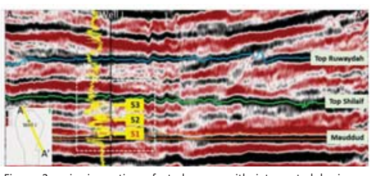

Figure 2: seismic section of study area with interpreted horizons (ADNOC internal study, 2019).

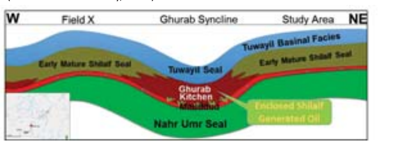

Figure 3: Charging and sealing theory of Mauddud (ADNOC internal study, 2019).

2. Workflow

The proposed workflow integrates the petrophysical and rock physics analysis with pre-stack seismic inversion and Bayesian classification to characterize the seal potential and distribution (Figure 4). The rock physics analysis constrains target seal properties using elastic attributes. Prior to the seismic inversion, it is essential to perform detailed quality control (QC) and pre-conditioning of seismic and well data (frequency filtering, trim statics, etc.). The pre-stack seismic inversion is conducted based on conditioned super gathers, angle dependent wavelets and low frequency model, with main outputs including P-impedance (Zp) volume and velocity ratio (Vp/Vs) volume. After the QC and analysis of inversion results, Bayesian classification is applied to identify the most probably distribution of target seal.

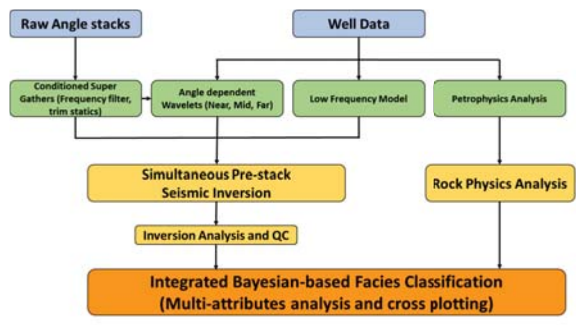

Figure 4: Schematic representation of workflow and methodology adopted in the study.

3. Petrophysics and Rock Physics Analysis

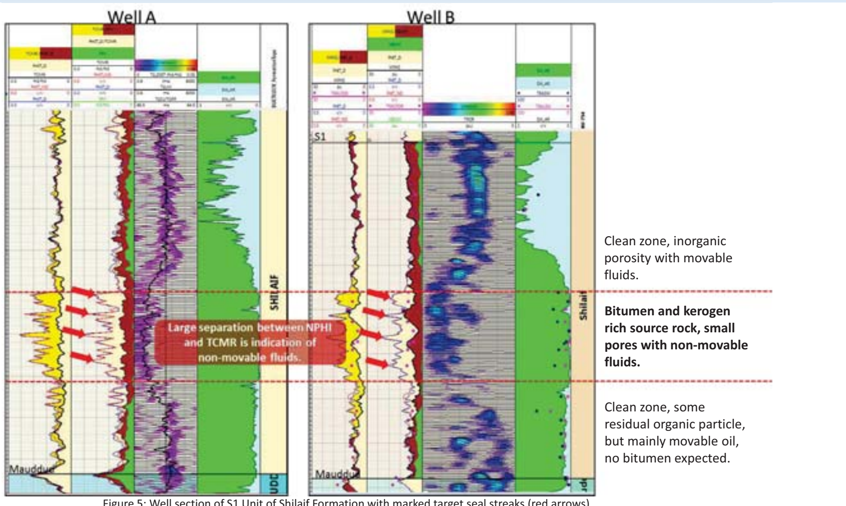

Figure 5: Well section of S1 Unit of Shilaif Formation with marked target seal streaks (red arrows)

The well logs have shown a good indication of the existence of non-movable fluids by the large separation between the porosity from neutron density (PHIT_ND) and the porosity from nuclear magnetic resonance measurements (TCMR) (Figure 5) (Steiner et al. 2015 and 2016). The core analysis also confirmed that the non-movable fluids are with high content of bitumen. Three lithologies can be identified from well logs:

- Clean mudstone characterized with inorganic porosity and low total organic content (TOC);
- Mudstone with organic porosity, partly filled with elevated TOC;
- Bitumen-rich mudstone. There is large separation between PHIT_ND and TCMR because the viscous fluids with no mobility and kerogen cannot be detected by nuclear magnetic resonance measurements (NMR).

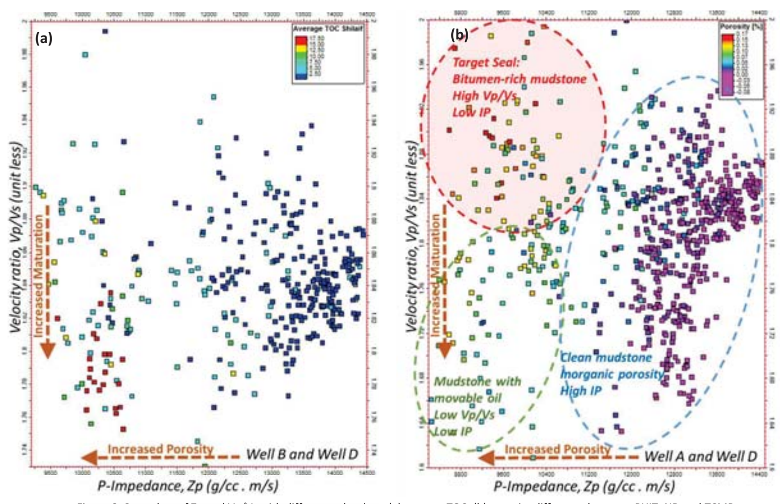

Figure 6: Crossplots of Zp and Vp/Vs with different color data: (a) average TOC, (b) porosity difference between PHIT_ND and TCMR

Crossplots of several properties over the target interval were analyzed to see if there is any possibility for lithology discrimination (Figure 6).

The Vp/Vs and P-Impedance crossplot showed the best separation between three lithologies identified by well logs. The target seal with high content of non-movable bitumen is of high Vp/Vs and low P-impedance. With the increase of maturation, the mudstone with movable oil is of lower Vp/Vs and low P-impedance (Bredesen et al. 2015 and Zhao et al. 2016). The clean mudstone with inorganic porosity is with highest P-impedance and variable Vp/Vs.

4. Pre-stack Seismic Inversion

Based on the rock physics analysis, P-impedance by itself is not able to separate target seal. Thus, the pre-stack seismic inversion with Vp/Vs output is conducted. Seismic conditioning is performed to remove noise and enhance amplitude, bandwidth and alignment and to condition the data specifically for quantitative interpretation. Statistical angle dependent wavelets (near, mid and far) are extracted from the conditioned super gathers. Figure 7 shows the seismic-well correlation panel for one of the 6 wells used in pre-stack seismic inversion. Deterministic wavelets using wells are extracted and there is good correlation between synthetic traces from well logs and composite trace from seismic.

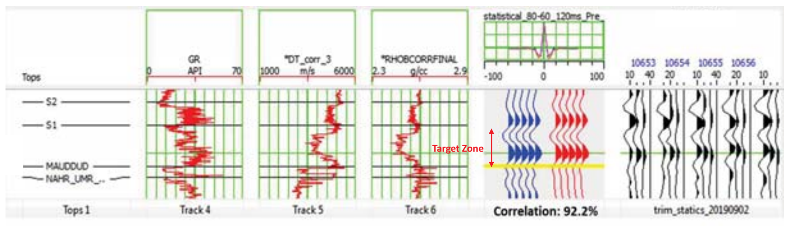

Figure 7: Seismic-well correlation panel (synthetic traces are plotted on the left in blue and composite trace plotted on the right in red)

Prior to apply the seismic inversion parameters to the whole volume, inversion analysis is essential to see how well the analysis inversion succeeded. Figure 8 shows generally there is good correlation (higher than 92%) around the 6 wells used in the inversion.

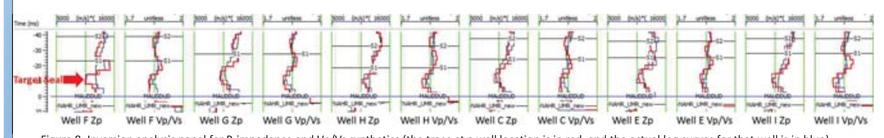

Figure 8: Inversion analysis panel for P-impedance and Vp/Vs synthetics (the trace at a well location is in red, and the actual log curves for that well is in blue).

The seismic sections presented in Figure 9 are used to QC the inversion outputs Zp and Vp/Vs. The lateral heterogeneous distribution and good match between synthetics and volumes within target zone indicate satisfactory inversion results.

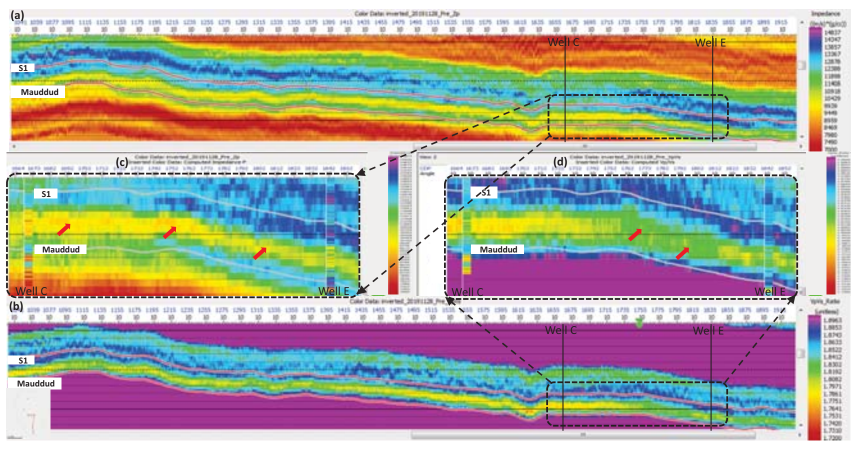

Figure 9: Seismic sections of (a) P-impedance and (b) Vp/Vs along well C and well E. The target seal is in between the red horizons S1 and Mauddud (pointed by red arrows). The area within black dashed squares are zoomed in (c) and (d)

The good positive correlation inside S1 between results from inversion and well log measurements (P-impedance: 75%, Vp/Vs: 85%) assures the reliability of next stage analysis of Bayesian-based lithology classification.

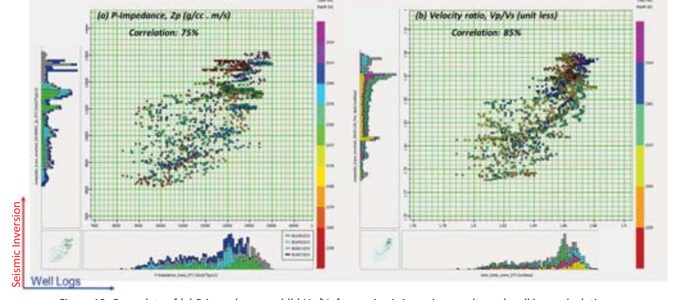

Figure 10: Crossplots of (a) P-impedance and (b) Vp/Vs from seismic inversion results and well logs calculations

5. Bayesian-based Lithofacies Classification

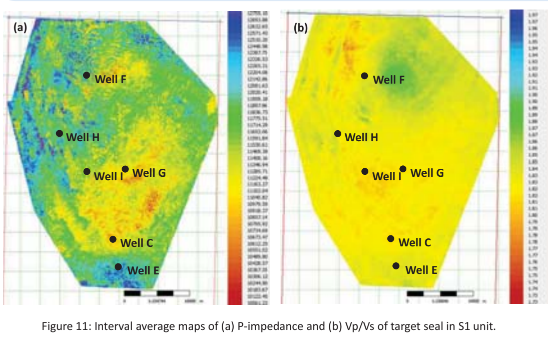

Figure 11: Interval average maps of (a) P-impedance and (b) Vp/Vs of target seal in S1 unit.

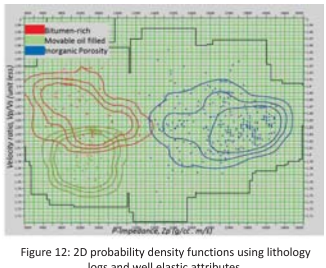

Figure 12: 2D probability density functions using lithology logs and well elastic attributes.

Figure 11 shows the distribution of generated P-impedance and Vp/Vs within the target seal in S1 unit. There is distribution of relative low P-impedance value in northeast and south of study area (Figure 11 (a)). However, only northeast are with relative high Vp/Vs (Figure 11 (b)).

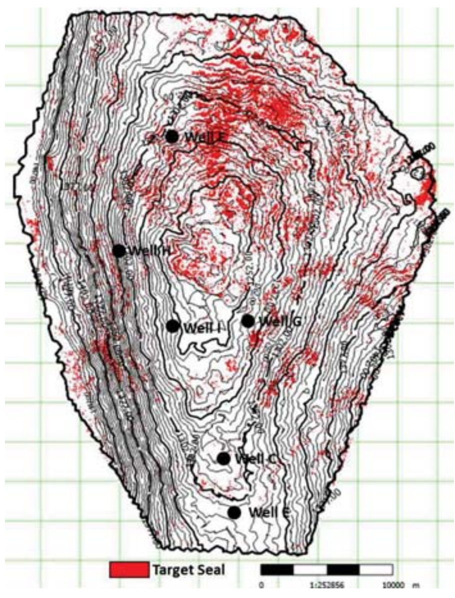

Figure 13: Interval average maps of final most probable seal distribution (highlighted with red color) from lithofacies classification analysis

Firstly, 2D probability density functions (PDF) are generated to correlate the well's logs to the seismic derived P-impedance and Vp/Vs (Figure 12). The Bayesian classification considers 3 classes: (1) bitumen-rich mudstone (identified in red in Figure 12), which is considered the target seal in this study; (2) movable oil filled mudstone; and (3) inorganic mudstone, which refers to low TOC.

Secondly, the PDF are applied to the full volume to extract the target seal lithology distribution with highest probability (Russel 2016). The Bayesian-based classification considering P-impedance and Vp/Vs volumes is applied to extract the lithofacies with low P-impedance and high Vp/Vs.

As depict in Figure 13, that shows the interval average map of seal distribution probability, the target seal in S1 unit of Shilaif Formation with high TOC and non-moveable bitumen at an early maturity is most probably present in the northeast part of the study area. This observation is consistent with well logs correlation results.

6. Conclusions

In this work we developed an adaptive workflow to characterize seal potential and distribution by integrating petrophysical and rock physics analysis of rock properties and pre-stack seismic inversion techniques. The essential part of integration is the application of Bayesian-based classification technique to predict the area away from well control.

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