Geostatistical Reservoir Characterization of Deepwater Channel, Offshore Malaysia

Trisakti Kurniawan and Jahan Zeb, Petronas Carigali Sdn Bhd, Jimmy Ting and Lee Chung Shen, CGG*

Summary

A quantitative interpretation was carried out in order to improve geological model and de-risk the prospect in the next exploration drilling campaign. Recently drilled exploration wells based on conventional seismic interpretation drilled through channel levee instead of the targeted channel core. Vertical resolution, reservoir quality, distribution and continuity of the channel feature are the main risks. A geostatistical inversion guided by rock physics modeling and deterministic inversion has been conducted to improve resolution, analyze the rock character and deliver probabilistic reservoir properties analysis as part of risk assessment. The results show that this technique improves the mapping of channel features associated with porosity and volume of clay distribution in comparison to the deterministic inversion or conventional seismic interpretation.

Introduction

This survey is located at offshore Malaysia, where the depositional system is complex and heterogeneous. The primary reservoir target is clastic sediment at Cycle IV-V. In order to re-evaluate previously drilled fault blocks, sequence stratigraphy has been used to generate the geological model. Subsequently, three wells were drilled at two different channel branches: Well-A and Well-B drilled through channel levee interval; Well-C unfortunately does not penetrate the main target interval due to drilling issue.

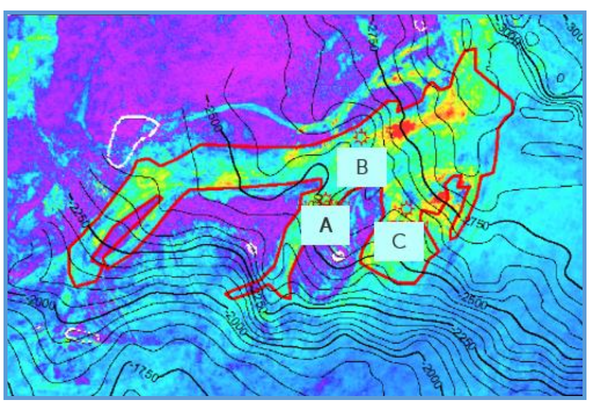

Figure 1: Time structure map overlaid with RMS amplitude over the target reservoir. There is no structural component within the prospect area.

The prospect is high risk with no structural trap element as shown in Figure 1. The initial exploration program was prepared by relying on the amplitude distribution only and it was expected to drill into the channel core but unfortunately ended up to be channel levee. The placement for the next two wells (Prospect 1 and Prospect 2) will be based on the analysis of this study aiming to hit the core channel features.

Rock Physics Analysis

Initial observation of the measured sonic log was not encouraging due to borehole quality. Inconsistent compaction trend at the massive shale interval was observed although the distance between the wells is relatively close. Therefore, conditioning of log data and the petrophysical analysis was reinitiated. The log data QC over the primary reservoir target shows that sands are harder than shales. A typical velocity-porosity trend in the sand-clay mixture system (Marion et al, 1992), has been observed as displayed in Figure 2. The contact cement line corresponds to the case where the rock is formed by quartz-cement rims growing on sand grains. Within the boundaries, velocity drastically increases with only slight decrease in porosity.

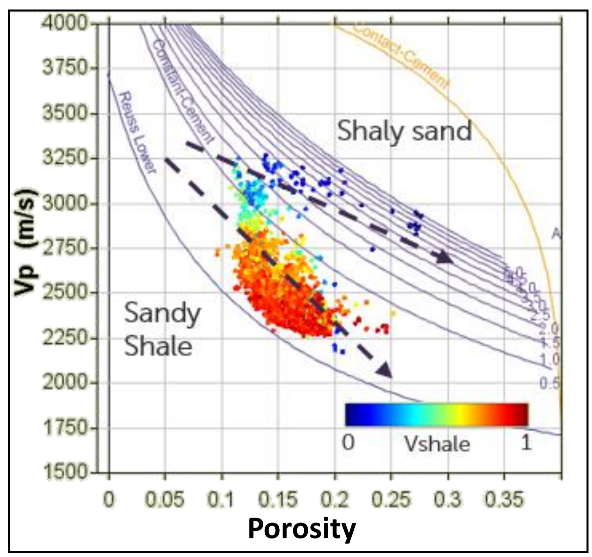

Figure 2: Velocity – porosity trend over the interval of interest. The trend is following rock physics conceptual model of Marion et al (1992).

A set of elastic logs was constructed using the modified Xu-White approach as presented by Sams and Focht (2013). This technique focuses on developing a rock physics model to predict elastic logs, such as P-velocity, S-velocity and Density over large interval using variable aspect ratio. The most critical and important key is having consistent model for petrophysics and rock physics. Inconsistency in the petrophysics is the root cause of the problems at rock physics modeling stage. Figure 3 shows log plot with variable aspect ratio extracted from both P and S-sonic log data. A comparison between conditioned log and modelled log was also presented in the log panel, where comparison between both logs shows relatively good match.

Seismic Inversion

Sensitivity and feasibility analysis based on well data was performed to determine the best geophysical technology for this particular study. It is found that combination of P-impedance and Vp/Vs ratio are the best parameters to define both lithology and fluid distribution. Simultaneous AVO/AVA inversion (Contreras et al, 2006) integrates well data and seismic information for a better control in geological determination. The challenge and problem happen in the construction of low frequency model (LFM) in this early exploration stage. Well interpolation and extrapolation of channel sand properties through stratigraphic layers over the whole study area might not be a good option for this case. Besides, the quality of the available seismic velocity is doubtful and it does not conform to the geological structure. Thus, a simple shale compaction trend workflow was selected with iterative inversion and update of the low frequency information through simultaneous inversion and Bayesian facies estimation procedure (Pendrel, 2015).

Geostatistical inversion (GI) was brought into the project with the expectation of mapping the thin bed reservoir with good porosity, and takes advantage of its capability to integrate with many types of data. Through geostatistical inversion, distribution of reservoir properties, e.g. porosity and volume of clay can be derived from elastic properties through co-simulation as the ultimate products. Geostatistical inversion does not require a LFM as input data, hence minimizing the bias on the absolute inversion results to the interpolation of well data. The other inputs like seismic partial stacks, horizons, wavelets and time-depth relationships were consistent for both deterministic and geostatistical inversion. The aim is to run the GI with minimum prior constraints from well logs and horizons. Just two main interest horizons were used to build the solid model for GI. Lithology (facies) definition and probability information were developed using well data. Although there are three wells, only two of them (Well-A and Well-B) were used. Well-C was dropped due to log data quality issue. The elastic logs derived from rock physics modeling were used as they provide more reliable histograms and probability density function (PDF) information. The results of deterministic and geostatistical inversion are consistent as displayed in Figure 4. Both results were mainly derived from seismic amplitudes, with geostatistical result showing more details coming from histograms and variograms.

Reservoir properties mapping

Three different lithologies were generated for detail reservoir mapping: high porosity sand, low porosity sand and shale. Sand and shale are defined based on cut-off of 0.4 on volume of clay. High porosity and low porosity sand are defined using a cut-off at 17% porosity. Crossplot of elastic with reservoir properties is shown in Figure 5. P-impedance shows higher standard deviation for both porosity effective and volume of clay compared to Vp/Vs ratio. A co-simulation process has been performed in order to produce porosity and volume of clay as part of reservoir effectiveness assessment. Both P-impedance and Vp/Vs ratio from geostatistical inversion have been used as input in co-simulation, with reservoir properties simulated laterally away from the well locations. Two different channel branches become much clearer after geostatistical inversion. The continuity of the channel features is also improved. Based on Figure 6, inversion can be observed as an effective way for amplitude detuning, which otherwise can be misleading for seismic interpreter who work on reservoir distribution based on amplitude analysis. Based on analysis of GI results, the well planning of Prospect 1 is maintained while Prospect 2 is dropped.

Conclusions

Geostatistical inversion with minimum prior constraints and without the use of LFM interpolated from well data has been successfully performed. The result is consistent with the deterministic inversion indicating the main lateral information was driven by the seismic amplitudes. Improvement on the channel features was successfully achieved in the GI result, avoiding mis-interpretation based on amplitude analysis. Future well planning is reconsidered based on the result from this study.

Acknowledgement

The authors would like to thank the PETRONAS management for the permission to publish the paper. Special thanks to Exploration Advanced Geophysics (XAGP) team and colleagues in Sarawak Exploration Department. Acknowledgments are also given to CGG GeoSoftware Kuala Lumpur and Houston office.

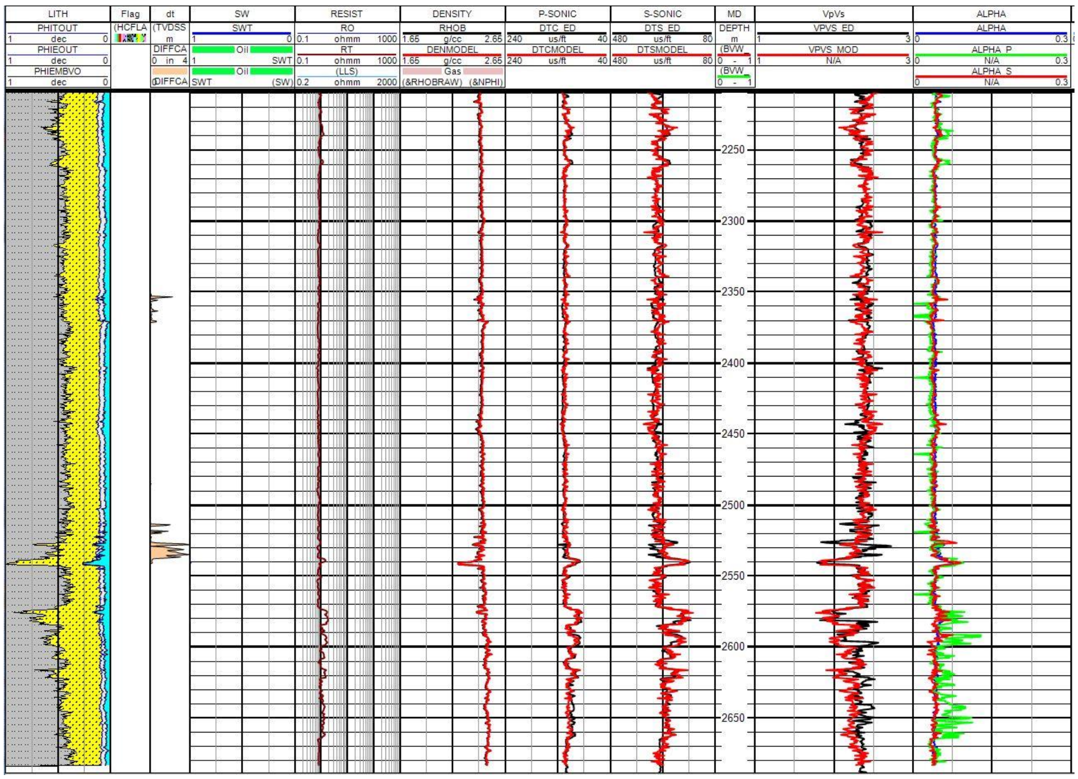

Figure 3: Log plot display of Well-A. Alpha (aspect ratio) curves are displayed in the right most column of the plot. Two different aspect ratio curves were initially generated from P-sonic (Alpha P – green line) and S-sonic (Alpha S – red line). The two Alpha curves are expected to be consistent, however large differences are observed near to well TD (green line). The average of both was generated. In order to give geological trend, the final aspect ratio was delivered as a function of porosity, volume of clay and depth in subsea through multi-curve regression. As a result, modeled elastic logs (red curves in DENSITY, P-SONIC and S-SONIC columns) have a good match with the measured logs (black curves).

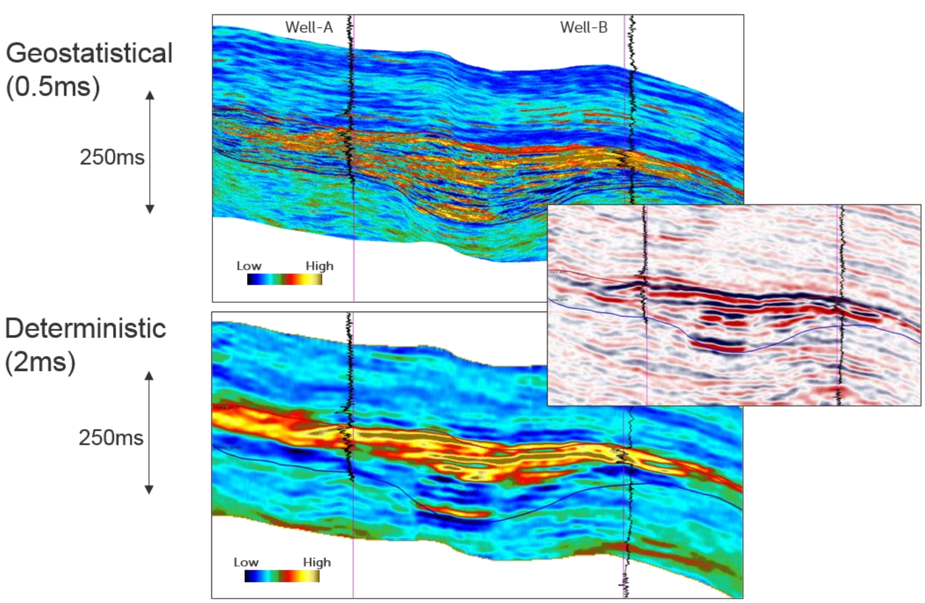

Figure 4: Comparison of deterministic (bottom) and geostatistical (top) inversion results. The results are consistent and driven by seismic amplitudes with good agreement to well data.

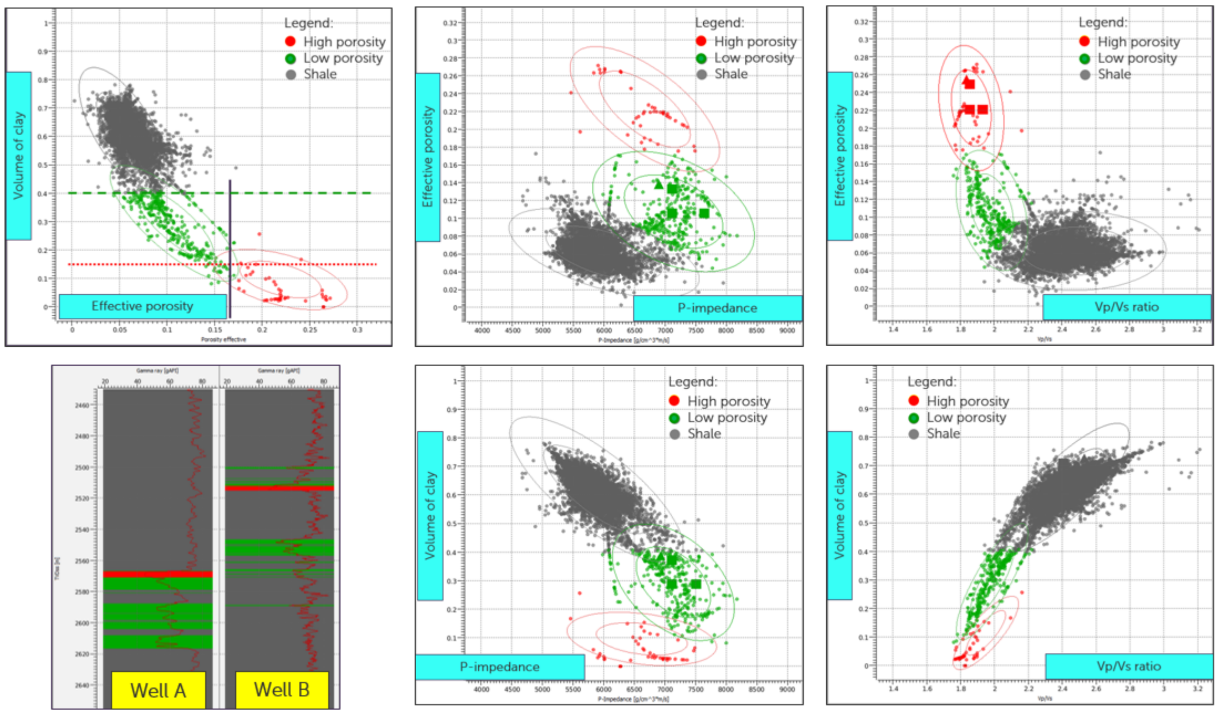

Figure 5: Crossplot analysis of lithology classification and relationship between elastic properties and reservoir properties. A thin bed of good porosity sand is observed from Well-A and Well-B.

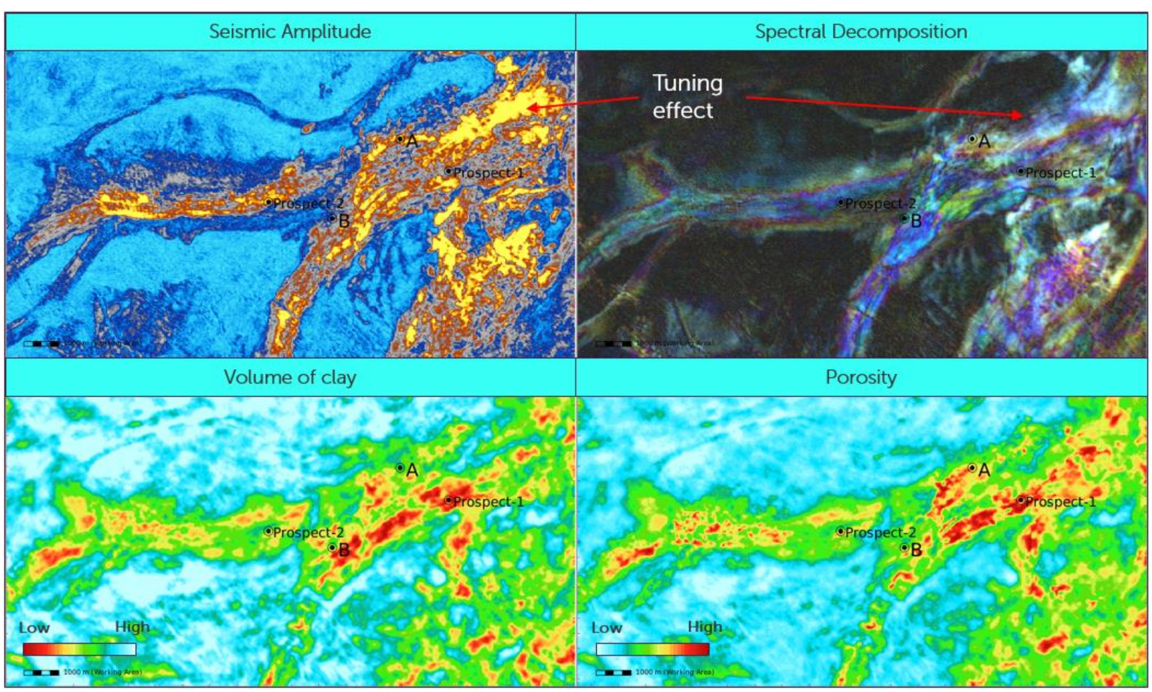

Figure 6: Stratigraphic horizon slices of seismic amplitude, spectral decomposition; together with volume of clay and porosity from co-simulation. The continuity of the main channel features can be observed in the co-simulated results, without the tuning effect. Based on this analysis, the well planning of Prospect 1 is maintained while Prospect 2 is dropped.

EDITED REFERENCES

Note: This reference list is a copyedited version of the reference list submitted by the author. Reference lists for the 2016 SEG Technical Program Expanded Abstracts have been copyedited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Contreras, A., C. Torres-Verdin, and T. Fasnacht, 2006, AVA simultaneous inversion of partially stacked seismic amplitude data for spatial delineation of lithology and fluid units of deepwater hydrocarbon reservoirs in the central Gulf of Mexico: Geophysics, **71**, no. 4, E41–E48, http://dx.doi.org/10.1190/1.2212276.

Marion, D., A. Nur, H. Yin, and D. Han, 1992, Compressional velocity and porosity in sand-clay mixtures: Geophysics, **57**, 554–563, http://dx.doi.org/10.1190/1.1443269.

Pendrel, J., 2015, Low frequency models for seismic inversions: Strategies for success: 85th Annual International Meeting, SEG, Expanded Abstracts, http://dx.doi.org/10.1190/segam2015-5843272.1.

Sams, M., and T. Focht, 2013, An effective inclusion-based rock physics model for a sand–shale sequence: First Break, **31**, 61–71.

Xu, S., and R. E. White, 1996, A physical model for shear-wave velocity prediction: Geophysical Prospecting, **44**, 687–717, http://dx.doi.org/10.1111/j.1365-2478.1996.tb00170.x.