Optimal use of seismic inversion derivatives in stratigraphic interpretation and geological modelling

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Keywords

Seismic Inversion, Stratigraphic Interpretation, Acoustic Impedance, Geological Modelling

Summary

In this study a novel workflow is developed where a sequence stratigraphic framework is built and integrated with seismic inversion driven acoustic impedance with the aim of building a realistic geological model for an oil field located in, offshore Sarawak, Malaysia. Sequence stratigraphic concepts have been used to analyze the petroleum geology of the field with integration of recently drilled culmination in fifteen surrounding wells. Sequence boundaries, marine flooding surfaces and parasequence set patterns were used to identify three important sea-level drops, matching the short-term eustatic global curve for this interval of time. These three third-order depositional sequences contain the bulk of estimated reserves for the whole field. Simultaneously seismic inversion was used to predict acoustic impedance volume. Stratigraphic framework and acoustic impedance were integrated together for geological modelling with the ain of optimizing development well locations. The results reveal optimization of well tops and visualization of sand bodies for a geological modelling prospective. The ultimate goal is optimum reservoir characterization and reservoir management which leads to success and reduce uncertainties in field development programs.

Introduction

In the current age of declining oil prices, mature fields matter today more than ever. About 70% of the current world oil production is from mature fields. As the industry keeps pushing the limits of exploration and production into marginal fields, geoscientists must create more predictive earth models in order to maximize exploration and development successes. To unlock the remaining potential from these fields, new wells need to be implemented by utilizing technological advancements in reservoir characterization, well engineering and reservoir engineering.

Stratigraphic interpretation provides a basis for chronostratigraphic correlation of sediments and is a valuable exploration and reservoir development tool for petroleum industry. This is a modelling technique used in stratigraphic and basin analysis to understand the depositional sequence geometries and stratigraphic architecture of a sedimentary basin. It also correlates on both regional and field-scale, coupled with an understanding of depositional environments and the roles of accommodation space with sediment influx to aid the reconstruction of palaeogeography and prediction of temporal and spatial relationships between source, reservoir and seal facies. Furthermore, it may help in identifying new reservoirs within existing oil and gas field.

On the other hand, seismic surveys are routinely performed to gather information about the geology and fluid fill of hydrocarbon fields. Seismic data, even when it has relatively low resolution can still deliver a structural model for the reservoir. The availability and coverage area of the data provide valuable information to constrain the reservoir model. Geophysicists are able to extract quantitative information about reservoir rocks and fluid parameters from seismic data using seismic inversion methods to characterize rocks and fluids; hence, enhancing the understandings of reservoir characterization in the field.

The objective of this study was to conduct a stratigraphic interpretation and to integrate this with the interpretation of seismic derivatives, e.g. inversion derived acoustic impedance for a geological modelling prospective in an ongoing field development program for a field located in offshore Sarawak Malaysia (Fig.1). This paper focuses on improving reservoir understanding by using seismic inversion derivatives and stratigraphic framework building for geological modelling.

Materials and Methods

Sequence Stratigraphy

Sequence stratigraphic concepts were used to analyze the petroleum geology of the field by identifying sequence boundaries, marine flooding surfaces and parasequence set patterns to capture three important sea-level drops, matching the short-term eustatic global curve for this interval of time (Fig.2). These sequences contain the bulk of estimated reserves for the whole field.

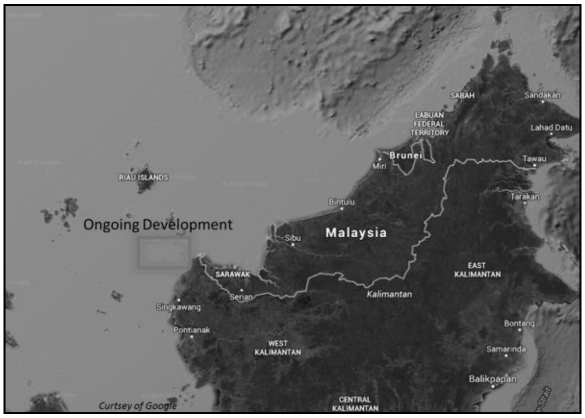

Figure-1: Location Map of the study area marked as 'ongoing development'

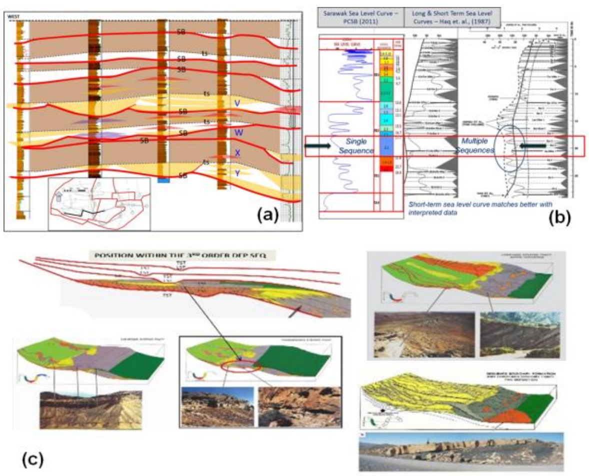

Figure 2: (a) Identification of main surfaces, sequence boundaries and parasequence set patterns to correlate genetically associated units from different wells. (b) Three important sea-level drops, matching the short-term Sarawak Sea Level curve (PCSB-2011). (c) The sequences are interpreted to be placed in a lower coastal plain environment.

Enhanced High Frequency (EHF) Processing and Seismic Inversion

EHF process deploys an innovative filtering technique to 3D seismic volumes, enabling the full bandwidth potential of the data to be exploited. In several projects, we have seen significant bandwidth improvements with little added noise and excellent well ties, adding considerable value to the interpretation. The frequency split spatial filtering technique used in EHF can also be deployed to expand the low-frequency bandwidth. This reduces the reliance of inversion products on background models and increases the range of bed thicknesses which can be resolved by the seismic alone.

Developing accurate and high resolution reservoir models imply integration of data from different sources in varying scales, which is one of the major challenges in reservoir characterization. Relatively low resolution of seismic data could only offer a structural model for the reservoir but its availability and areal coverage suggests that it has valuable information to constrain the reservoir model. This information could be extracted by the process of seismic inversion that transforms seismic data into a quantitative rock property, descriptive of the reservoir.

Seismic inversion helps to characterize rocks and fluids from seismic data by removing the wavelet, hence deriving acoustic impedance from reflection coefficient with a low frequency model to infer rock properties and to deliver an interpreted earth model. These results are integrated with stratigraphic framework to plan the development wells. The seismic data was re-processed with enhanced high frequency technique (EHF^{TM}) and integrated with vertical seismic profile (VSP) data for seismic inversion. An example of seismic inversion, VSP and geobody extraction is shown in Fig. 3.

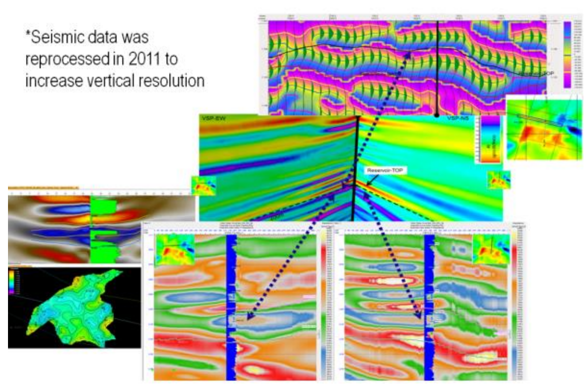

Figure 3: These EHF seismic and VSP data were integrated for interpretation to revise and estimate the reserves.

Results and Discussion

A stratigraphic framework was built to interpret sequence boundaries. Based on the marine flooding surfaces and parasequence set patterns, four main sequence boundaries (Fig 4a) were identified and further correlated with the 3D seismic interpretation. A total of 15 wells were used for correlation. Three important sea level drops were identified matching the short-term eustatic global curve for this interval of time. A post stack seismic inversion based algorithm (Figure 4b and c) was used to predict acoustic impedance. A good correlation with well impedance was achieved. Sequence stratigraphic interpretation and seismic inversion driven acoustic impedance were interpreted together and calibrated with well data. Based on the integrated interpretation potential, development well locations were optimized with reduced uncertainties.

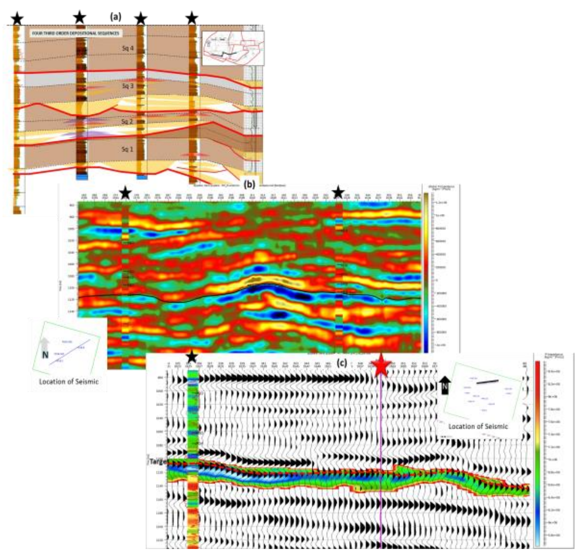

Figure 4: Figure shows Stratigraphic interpretation, seismic inversion driven acoustic impedance, and captured geobody at target level. Black stars show well locations. (a) Four sequence boundaries were identified and marked as sq1 to sq4. (b) Acoustic impedance filtered 10-70hz section shows good calibration at well location; (c) absolute impedance and captured geobody calibrated with a well, red star shows potential drilling location.

Stratigraphic interpretation helped in the optimization (Fig. 5) of well tops and seismic inversion based geobody extraction predicted the lateral extent of sand bodies. The results reveal that integrated interpretation of the stratigraphic framework, together with quantitative seismic attributes e.g. acoustic impedance, helps in the creation of a field development well portfolio with reduced uncertainties.

To understand the reservoir sand distibution, seismic inversion predicted acoustic impedance is used. Vp/Vs ratio and Acoustic Impedance properties are crossplotted together to capture the best sand in interpreted logs and seismic inversion driven acoustic impedance section (Fig.6). Best sand distribution in 3D was predicted. Predicted sand distribution (3D geobody) is used as a secondary property in geological modelling and the uncertainities during well location optimization were reduced.

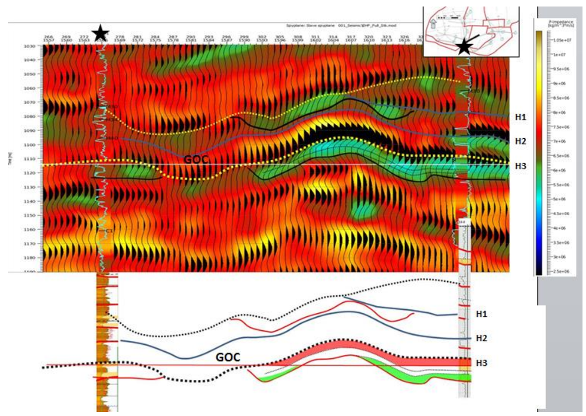

Figure-5: Predicted acoustic impedance from seismic inversion. The impedance derived from seismic and wells were filtered at seismic frequency (10-70Hz). A good calibration with well impedance is shown. The impedance section is showing important erosion at the base of a sequence boundary (refer to Figure-4a, sq4), and identified channel at H2. As GOC is positioned near to H3, the green colour in the lower figure represents the presence of oil and the pink colour shows the presence of gas at H3 level.

Conclusions

The integrated interpretation of stratigraphic framework together with quantitative seismic attributes e.g. acoustic impedance helps to improve reservoir characterization and enhance the understandings of sand distributions within the field. Integrated interpretation of seismic inversion driven derivatives and sequence stratigraphic framework helps in reducing uncertainties in geological modelling process and further in optimizing the drilling locations. This imperative input enables the team to identify strategic drilling locations for field development portfolio, hence, reducing subsurface risks and uncertainties.

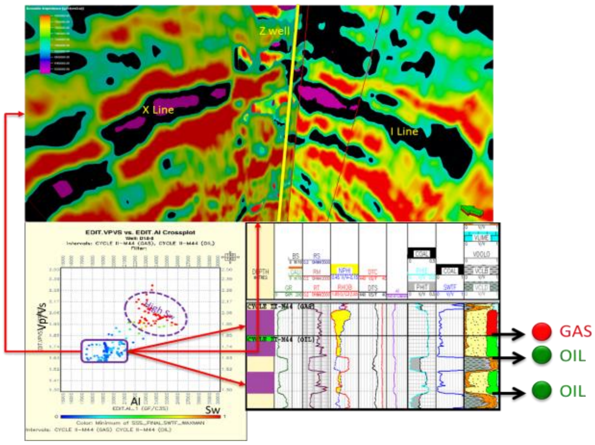

Figure 6: Full bandwidth Impedance is used to understand the best sand distribution, which is represented by the purple polygon in the cross plot (AI vs Vp/Vs colored by Sw at log scale for Z well) corresponds to the highlighted zone (black) in the 3D view (inversion scale) and purple bands in the log view.

References

Rajput, S., & Ring, M., 2014. The Role of Seismic Inversion in Exploration and Development: Adding Value and Reducing Uncertainties. Offshore Technology Conference. doi:10.4043/24878-MS

Acknowledgements

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