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Simultaneous Inversion for Facies Distribution: A Case Study from West Tryal Rocks, Australia

Abstract

We present a workflow for the simultaneous inversion of multiple angle stacks to derive models of elastic properties of the subsurface. These elastic properties are used as input for estimating lithology and fluid probability models using Bayesian classification. Interpretation using Bayesian classification reduces the user bias and makes the process more data driven and robust. A real example from West Tryal Rocks, Western Australia shows that uncertainty associated with facies classification due to overlap of elastic properties of different facies can be efficiently quantified using probabilistic interpretation under framework of Bayesian inferences.

Introduction

Subsurface geological models serve different purposes in the various stages of life of an oil and gas field, i.e. exploration, appraisal, development and production. Typical applications range from structural interpretation, prospect ranking, reserve estimation, planning appraisal and development well locations, and mapping bypassed pay as well as fluid movement for reservoir management. One major task of a subsurface geoscience team is to generate realistic geological models to serve the above objectives using multi-measurement data and a multidisciplinary approach. Commonly used datasets for generating these geological models are well logs and surface seismic besides geological concepts and knowledge of depositional setup. Seismic reservoir characterization methods comprising deterministic inversion- whether separate or simultaneous- integrate the information from seismic amplitude or amplitude variation with offset (AVO) and well measured acoustic/elastic properties like acoustic and shear velocities along with density to yield the best subsurface model. As the seismic data is band limited in nature, we require low frequency elastic properties, viz. acoustic impedance (AI), shear impedance (SI) or the ratio of acoustic and shear velocities (Vp/Vs) to derive the corresponding absolute values which can be subsequently used as input to estimate reservoir properties like porosity, volume of clay and water saturation under a framework of Rock Physics. In general, low frequency models are built using interpolation of the filtered well logs through a structural-stratigraphic framework using interpreted horizons and faults and knowledge of depositional setting. Seismic velocities are quite often used as trends for the low frequency model. Lithology, porosity and fluid content are key parameters required for decision making at various stages of exploration, appraisal and development. It is also important to know the uncertainty associated with these parameters to assess the risk involved while using these properties in decision making. Interpretations of attributes derived from inversion results play important roles assessing the uncertainty as well as in quantifying it. The conventional techniques to interpret inversion results using cross-plot zones or histogram ranges of elastic properties to differentiate amongst various facies are quite subjective. These methods ignore the overlap of elastic properties of different facies and, thus, fail to account for the uncertainty in the interpretation which could be avoided through probabilistic interpretation of the results. Here, we present a novel workflow that not only circumvents the subjectivity in interpretation stated above and also captures the uncertainty in the interpretation of results. We propose the use of the time-honoured principle of Bayesian Inference that relates prior knowledge about an event with the likelihood of the event to estimate posterior probability or knowledge. In the present context, the stated event is the simultaneous inversion and prior knowledge is the facies distribution computed from petrophysical properties at the In Bayesian classification, we train a data set using elastic logs and interpreted facies. We generate probability density functions (pdfs) for different facies and validate the interpretation at the well locations. Once we get a good training set with acceptable validation, we apply these trained pdfs on the full volumes of inverted elastic properties in order to generate probability volumes for different facies. We apply this to a data set from West Tryal Rocks, Australia (Figure 1). Results from the simultaneous inversion of multiple seismic angle stacks, viz. Acoustic impedance and Vp/Vs have been interpreted in terms of facies probability volumes. The inverted acoustic impedance and Vp/Vs is also transformed into porosity using multi attribute regression for particular sand, M.

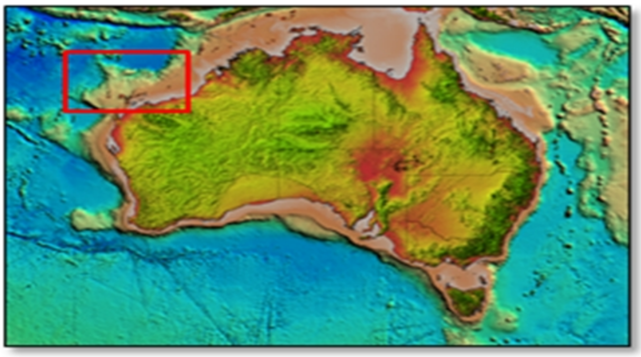

Figure 1: The Study area- Location of West Tryal Rocks.

Geology of the area

We follow Meath and Bird (1976) to describe the geology of the area and history of discovery. West Tryal Rocks gas field is located offshore at the western margin of the Barrow Sub-basin, in the Carnarvon Basin of Western Australia. It was discovered by West Australia Petroleum Pty Ltd in 1973 on a South Westerly extension of the Rankin Platform where, farther north, a number of major gas/condensate discoveries have been made by Burmah Oil Company of Australia Ltd since 1971.The productive structure at West Tryal Rocks lies at a depth of 3200 m in about 150 m of water. It consists of an elongate north-trending uplifted block of Triassic and possibly Lower Jurassic reservoir rocks called the Mungaroo beds. The block is unconformably capped by the Lower Cretaceous Muderong Shale which also provides the lateral seal across the bounding faults. The reservoir section dips to the north at a greater rate than does the sealing unconformity so that progressively younger pre-Cretaceous sediments subcrop the unconformity in that direction. Shales of Middle to Late Jurassic age in the Barrow Sub-basin to the East are believed to be the primary source of hydrocarbons, although the overlying Muderong Shale cannot be ruled out (Playford and Johnstone, 1959).The sands are mainly medium to very coarse grained and possess good porosity and permeability. Preliminary reserve estimates indicate that the field contains in excess of 28 x 10^9 m^3 of gas.

The West Tryal Rocks gas field is unique compared to the other Northwest Shelf fields, in that it is slightly overpressured and contains up to 28% of non-combustible gases-predominantly carbon dioxide and nitrogen. Additionally, the field possesses relatively fresh underlying formation waters with high concentrations of bicarbonate ions. There are 5 sand packs M, N, O, QRS and T as per the geological model. M sand is the major gas saturated pack and encountered in 3 wells.

Data and Methodology

Data available for the present study comprises of 3D partial angle stacks in the depth domain and basic logs in 3 wells, including acoustic wave along with the structural interpretation. The depth domain partial angle stacks are converted into time domain using the processing velocity. An angle range from 8-53 degree is present in partial stacks. The 53 degree stack is discarded because of the poor S\N ratio. The time domain angle gather are compensated for AVO offset scaling. Angle gathers need to be conditioned in an AVO friendly manner in order to improve the signal-to-noise ratio within the zone of interest between the M and T sand packs. The gather is further processed to flatten the events within the zone of interest in order to capture the correct amplitude variation with angle. The seismic is of reverse polarity i.e. increase in impedance is represented by a trough in the seismic signature. The seismic zone is further analysed for the bed resolution. Tuning thickness within the zone of interest is 35 m, hence we can resolve the top and base of thickness 17.5m from deterministic inversion. The M sands present in the area can be resolved using the deterministic inversion methodology. The objective of this work is to delineate the M sand hydrocarbon probability distribution. The workflow used in this study is shown in Figure 2.

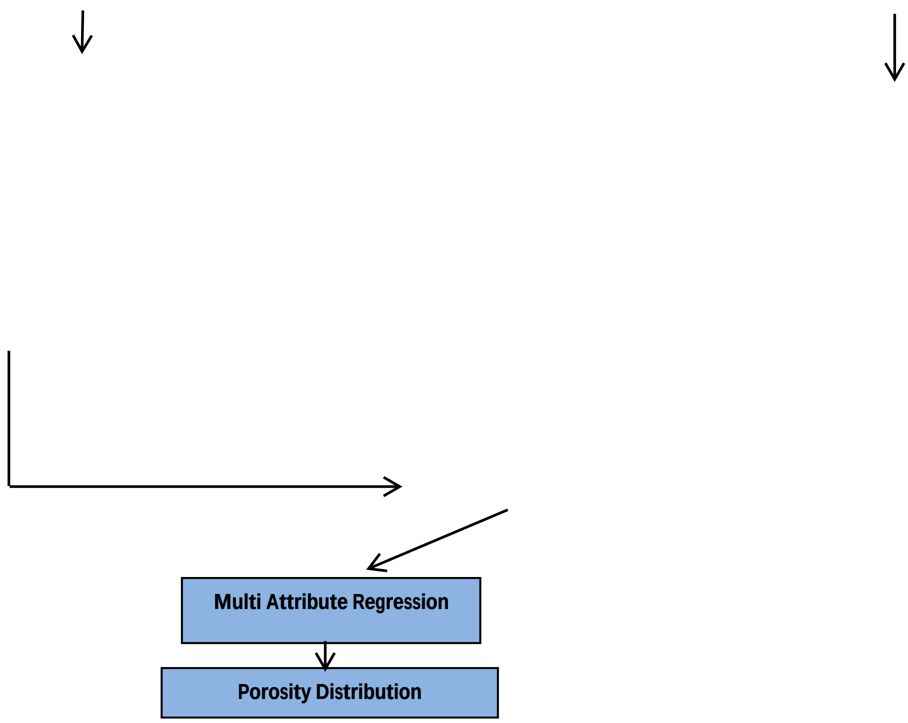

Figure 2: Workflow for seismic and well data conditioning, inversion and interpretation.

Out of the 3 wells available for this study 1 well has a recorded shear sonic log. A rock physics model is established on this well with a good prediction of elastic logs. This rock physics model is used in the other 2 wells to predict the missing shear sonic logs. With this, we have conditioned seismic angle gather, 3 wells with sonic, shear sonic, density logs and interpreted logs in terms of water saturation, porosity, volume of clay and facies log as shown in Figure 3.

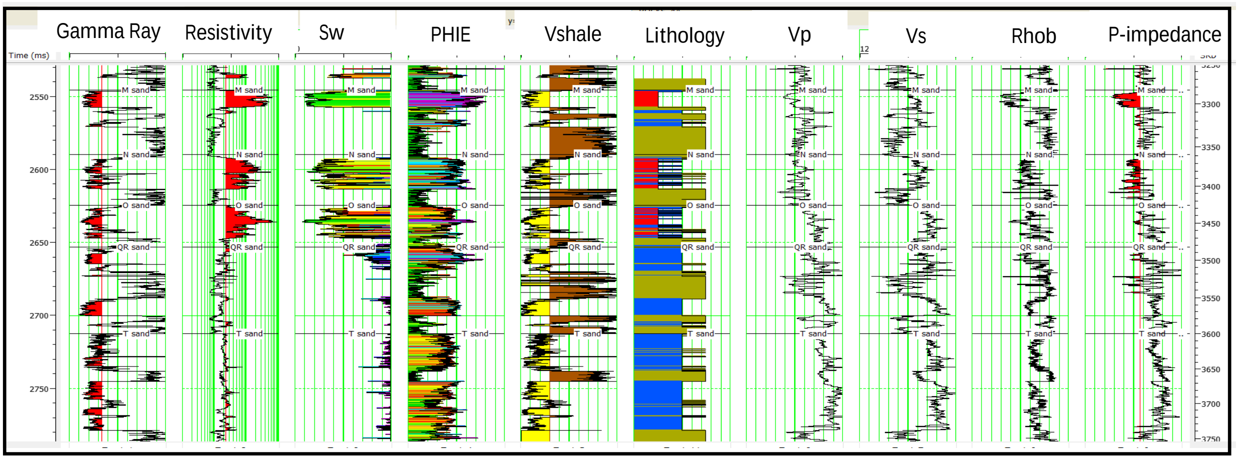

Figure 3: Measured and interpreted logs in well 4. Panels from left to right represent gamma ray, resistivity, water saturation, effective porosity, volume of shale, lithology derived from petrophysical properties, acoustic velocity, shear velocity, density and P-impedance respectively.

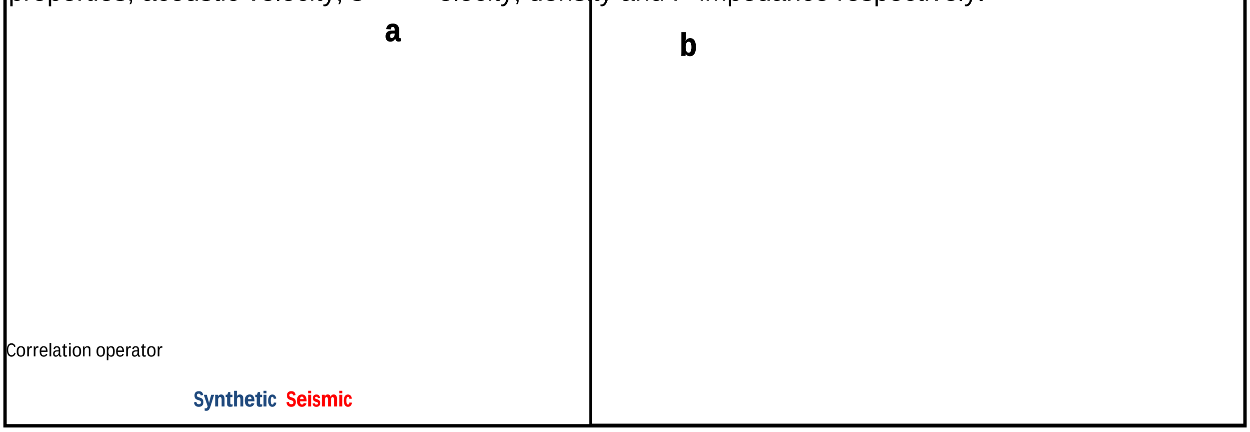

Figure 4: Well to seismic tie for Well 4(a) and its inversion analysis (b).

A good well to seismic tie is obtained for 3 wells using a statistical wavelet of 180 degree phase as shown in figure 4(a). Low frequency models for all three elastic properties to derive P-impedance, Vp/Vs and density are created using filtered elastic logs interpolated in the area guided by the structural interpretation.

Pre-stack inversion analysis is performed at the well locations in order to optimize the parameters for inversion as shown in Figure 4(b). Once the inversion parameters are optimized at the well locations, inversion is run onto the entire area in order to generate acoustic and shear impedances.

Results

Figure 5 shows the seismic data, inverted acoustic impedance and Vp/Vs along an arbitrary line passing through the three wells. Gamma ray in the wells is overlaid on the seismic track and measured P-impedance and Vp/Vs in the wells have been overlaid on their respective tracks for better comparison. The results show that both acoustic impedance and Vp/Vs derived from match quite well at the well location.

Figure 5: An arbitrary line passing through the three wells showing the seismic stack (top) acoustic impedance (middle) and Vp/Vs (bottom). Gamma ray, acoustic impedance and Vp/Vs logs from wells are overlaid on the respective sections.

Interpretation of these elastic attributes is the key point here. We are using the facies log from petrophysical interpretation for estimating prior lithofacies probabilities, to be used in Bayesian classification. We trained the elastic logs using facies at the well locations in order to generate probability density functions (pdfs) for the different lithologies, hydrocarbon (HC) sands, brine sand and shale as shown in Figure 6. A detailed methodology is given in Nieto, Delbecq, and Batlai (2013).

Figure 6: Probability distribution functions pertaining to the training dataset and validations in terms of prediction at the wells.

Litho-log	Classified logs (in percentage, %)		
	Hydrocarbon Sand	Brine Sand	Shale
Hydrocarbon Sand	74.6	24.7	0.7
Brine Sand	3.4	92.3	4.3
Shale	0.4	17.2	82.4

Table 1: Confusion matrix indicating the facies classification. The off-diagonal elements represent misclassifications of facies. For very good performance of the scheme, the off-diagonal elements should tend to zero.

This training data is validated at the well locations using a confusion matrix (Table 1). The confusion matrix is a very quantitative method of understanding how many samples of a lithology are correctly interpreted and how many samples of this lithology are wrongly interpreted as another facies. We derived a pdf with reasonable validation at the well location. These pdf's are then applied onto the entire dataset in order to generate facies probability distributions and a most-probable facies volume as shown in Figure 7. The HC sand probability and most-probable facies section shows the distribution of HC sand probability and most-probable facies in the section passing through all well locations. These probability models are in line with the geological model of sand distribution.

Figure 7: Bayesian classification results showing HC sand probability and most-probable facies with gamma ray curve overlaid on section

In order to compare the results from seismic amplitude interpretation and elastic attributes interpretation using facies probability, maps from these different results have been prepared as shown in Figure 8. In addition to the facies interpretation, the inverted acoustic impedance and Vp/Vs is also transformed into Porosity within the M sand using multi attribute regression (Hampson, Schuelke, and Quirein, 2001). A comparison of seismic amplitude, elastic attribute, predicted porosity and hydrocarbon sands probability is shown in Figure 8.

Figure 8: Shows the maps for seismic amplitude (a), acoustic impedance (b), Porosity(c) and HC sands probability (d) for M sand.

The seismic RMS amplitude map Figure 8(a) shows a high amplitude anomalous body in the area which coincides with low acoustic impedance region (b) delineating this anomalous body more clearly. Figure 8(c) shows the porosity distribution for M sand. The HC sand probability (d) shows the distribution of HC sand probability in the area. This reduces the uncertainty of seismic amplitude interpretation and thus aides in precise well placement.

Conclusions

We used Bayesian classification to derive the probability of hydrocarbon facies from Simultaneous Inversion of seismic data from the West Tryal Rocks gas field. Multi attribute regression using acoustic impedance and Vp/Vs have been used to derive porosity. Results show that there is significant benefit progressing from seismic amplitude interpretation to elastic attributes, Bayesian classification and multi attribute regression for porosity generation. We also showed that Bayesian classification is a more refined approach for the quantification of uncertainty in interpretation and removes user subjectivity. The probability volumes for different facies from Bayesian classification reduce the risk and uncertainty in the results of inversion interpretation. The interpretation of all the attributes derived from seismic, elastic attributes from simultaneous inversion and facies probability volumes from Bayesian classification help in determining the precise spatial distribution of reservoir facies, thereby reducing risks in well placement.

References

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