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Application of Simultaneous Inversion Characterizing Reservoir Properties in X Field, Sabah Basin

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Abstract. X field located between the East Baram Delta and Southern Inboard Belt, which is elongated northwest to southeast direction in Middle Miocene Sabah Basin. Previous studies were unable to differentiate the lithology and fluid distribution in the field by using conventional reservoir characterization approaches for example amplitude versus offset (AVO) analysis and post-stack deterministic inversion due to the low contrast in P-impedance between gas sand and shale. Thus, the goal of this approach is to obtain a reliable estimation of P wave velocity (V_P) . S-wave velocity (V_s) , and density (p). From these parameters, we predict the fluid and lithology properties for better reservoir characterization. A feasibility analysis was conducted and the results show that prediction of the hydrocarbon reservoir in X field is feasible using P-impedance and Vp/Vs. Consequently, the simultaneous inversion is carried out to derive the rock properties such as density, P-impedance, S-impedance, Lambda-rho (λp) (Incompressibility), and Mu-rho (μp) (Rigidity). The results from this study demonstrate the effectiveness of simultaneous inversion and the best parameters for enhancing the resolution and characterizing the hydrocarbon sand layer of the prospect.

1. Introduction

1.1 Background

Back in years, amplitude has only been used for prospect evaluation and reservoir characterization or development since the advent of bright spot Direct Hydrocarbon Indicator (DHI) technology. However not all bright spots are DHI, it can be happened when hard shale is overlying on the soft shale or brine sand, and when there is anisotropy caused by the presence shales or thinly bedded intervals [1]. Thus, it was best studied in AVO-inversion domain by classifying the AVO response from forward modelling and extract more information from the shear impedance seismic data at different offset that can highlight the fluid content and discriminate lithology in the reservoir [2].

Both AVO and inversion should work consistent with well log and vertical seismic profile (VSP) data. According to [3], elastic parameters can be obtained through prestack AVO inversion for reservoir characterization. Thus, the integration of seismic, geology, borehole, rock physics, and petrophysics are significant for the AVO inversion process. Inversion is a technique that convert the interface property or reflection coefficient from seismic data to a layer property which is known as P-impedance [4].

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Information of internal rock properties such as lithology, porosity or fluid type could be extracted from the amplitudes of inverted data set. From the inverted data, it is more ideal for us to do stratigraphic interpretation and reservoir characterization.

1.2 Problem Statement

In earlier study, reservoir characterization using post stack deterministic method to estimate acoustic impedance was attempted, but this method was unable to discriminate the reservoir and non-reservoir lithology in the field as both gas sand and shale are sharing almost similar P-impedance response. Thus, in most wells, the fluid contacts were not seen although the pressure data suggested that the contacts were close to the amplitude shut-offs and flat spot that can found in the given seismic. Besides, the field has also polarity issue and amplitude which increase the challenges to characterize the reservoir [1]. The associated seismic data quality and amplitude of certain area of prospect were poor due to wipe out of amplitudes caused by gas leakage.

From previous case study, X field was being abandoned before due to lack of hydrocarbon indication and the negative results from previous drilling activities. Thus, a combination of geological concepts and modelling with good quality of seismic and careful geological and geophysical evaluation were required for successful exploration and development for the prospect area.

1.3 Objectives

The main objective of this research is to discriminate the lithology and maps the fluid distribution of the hydrocarbon bearing reservoir by using simultaneous inversion method. The subsequent objectives to be achieved while carrying the study are:

- Estimate the reservoir properties such as P-impedance, S-impedance, density (p), Vp/Vs, Lambda-rho (λp) (Incompressibility), and Mu-rho (μp) (Rigidity) from the inversion results.
- Enhance the prediction of actual reservoir's condition to reduce to risk of drilling a dry well.
- Determine the best parameter for inversion process.

1.4 Scope of Study



Figure 1. (a) Location map of study area [5] (b) Base map for well location with Stage IVC unconformity surface (c) Seismic line across X field from A to A'

The study includes the 3D angle stacks seismic and well logs data from X field. The 3D seismic data are about 300 km2 (925 inline and 1981 crossline) with angle stacks at different ranges, near (5º-15º), mid (15º-25°), and far (25°-40°). Check shot and well logs from 8 deviated wells which required for both geological and petrophysical analysis were complete and ready for the study. These datasets will be loaded into Schlumberger Petrel and Hampson Russell software for further analysis. In this case study, only 3 wells will be emphasized which are SU-1(deviated), SEL-1 (vertical) and UJ-1(vertical). Figure 1 shows the location map, base map and seismic cross section of the study area.

2. Methodology

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Simultaneous Inversion GEOLOGICAL STUDY 1. Tectonic Setting 2. Stratigraphy HORIZON PICKING WELL TO SEISMIC TIE 1. Extract statistical wavelet I. Extract statistical wavelet I. Extract statistical wavelet I. NVERSION MODEL INVERSION MODEL Vp/Vs Application

The workflow in figure 2 describes the steps and processes carried out to achieve the objectives of this research that include lithology and fluid distribution of the hydrocarbon bearing reservoir, reservoir properties estimation, and reservoir's conditions prediction. Each of the methods used is discussed in relation to its applicability to the study of reservoir characterization of X Field in Sabah Basin.

Figure 2. Simultaneous inversion workflow

2.1 Feasibility Analysis

The cross-plot approach is applied on the respective wells, to determine feasibility of the simultaneous seismic inversion process on the dataset, before proceeding to the full inversion workflow. This step could help us to understand the quality of both seismic and well logs data. Figure 3 represent the cross plot of Vp/Vs ratio versus P-impedance at the hydrocarbon zone of interest at well SU-1, SEL-1, and UJ-1. From the cross plots, separation between the points scattered can be observed, and make it possible to differentiate hydrocarbon from claystone and brine sand from these elastic rock properties.



Figure 3. Cross plot of Vp/Vs ratio against P-impedance. (a) Well SU-1 (b) Well SEL-1 (c) Well UJ-1. (Red dots represent the gas sand, green dots represent oil sand, purple dots represent clay stone)

2.2 Wavelet Extraction and Well Tie



For a pre-stack data, it is highly expected that the seismic data will experience a continuous loss of high frequency energy from near to far offset [5]. Thus, each trace of CDP gather would have different wavelet representation. In this study, both statistical and respective well's wavelets from are extracted for comparison to determine which type of wavelet can generate better inversion results (figure 4).

For this study, well to seismic tie is important

Figure 4. Extraction of statistical group wavelet to examine the current depth-time conversion and optimizes it so that the generated zero-offset synthetic can optimally match the seismic. This step is crucial since the depth time curve derive only from sonic log is insufficient for the purpose.

2.3 Generate Low Frequency Model

A low frequency model (LFM) or initial model is basically an initial impedance volume to represent geological model of a field. The models cropped from 700ms to 2000ms are generated with the input of well logs data (P-wave velocity, S-wave velocity and density), angle gathers and the interpreted horizons. The simple model was built, with the values from the well logs are being extrapolated by using the log trend from all logs and the interpolation between the horizon of top reservoir and base reservoir is top lap to each other. This model able to provide data that will compensate for missing information in the seismic data at low end of spectrum. It can integrate the information and data from several sources, introduce trends, increase resolution, remove tuning and provide absolute results from the inversion. These models were then used as the input for inversion process.

2.4 Inversion Analysis and Modelling

After both wavelets and low frequency models have been obtained, the convolution process is carried out to generate PP synthetic trace by using Aki-Richard's equation (1), where, $c^{1}=1+\tan^{2}\theta$, $c^{2}=-8y^{2}+\tan^{2}\theta$, $c^{3}=-0.5$ $\tan^{2}\theta+2y^{2}\sin^{2}\theta$, $\gamma = V_{s}/V_{P}$, $R_{P}=$ P-reflectivity, $R_{S}=$ S-reflectivity, $R_{D}=$ Density-reflectivity [6]. In this study, Hampson Russel's Simultaneous Inversion algorithm will be used and applied to the volume. Three inverted volumes will be generated namely, inverted P-impedance (Zp), inverted S-impedance (Zs) and density. The inverted results will be quality checked by using the cross-plot approach and compare the results with the well data at the bandpass filter with cut off frequencies of 10/15-70/90H. Relationships between P-impedance, S-impedance, and Lame parameters were analysed for reservoir characterization.

$$R_{PP}(\theta) = c_1 R_P + c_2 R_S + c_3 R_D \tag{1}$$

3. Results and Discussion

3.1 Well Log Analysis

This is the first step to identify the reservoir of interest by considering the reservoir properties such as volume of shale, porosity and water saturation. The basis log used are gamma ray, density, neutron porosity, and resistivity logs. Whole formation was evaluated to identify the primary reservoir of this study. No core data available for calibration, input parameters were referred to the log analysis report from well SU-1.

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From this well log analysis, hydrocarbon zone can be indicated by density-neutron crossover. According to [7], presence of negative cross over for density and neutron log, with low gamma ray and high resistivity indicates the existence of hydrocarbon in a sandy reservoir. Figure 5 shows the petrophysical results for the control vertical well of this study SEL-1.

Figure 5. Results of petrophysical quick look from measured depth (MD) at well SEL-1

3.2 Inversion Analysis



Figure 6. Cross plots of reservoir properties for $\ln Z_S$ versus $\ln Z_P$ (a, c and e), and $\ln Dn$ versus $\ln ZP$ (b, d and f) in well SU-1, SEL-1 and UJ-1 respectively

Pre-inversion analysis is a platform for the interpreter to test variety of inversion parameters on selected well before applying to the seismic volume. It allows us to measure success of the inversion and analyse different possible outcomes resulting from different type of wavelets.

Since inversion is a non-unique process as there are many geological answers consistent with input seismic data. Thus, cross plots with background trend information were derived from well logs in the model relating variables of Zp (P-impedance), Zs (Simpedance), and density on a log-log scale to non-uniqueness. reduce the Linear relationship between these variables are assumed to be in the absence of hydrocarbon [6]. Thus, in this case, we are looking for deviations away from a linear fit in logarithmic space to identify the desired fluid anomalies as shown in Figure 6.

From the figures, the red lines indicate the current linear trend, which has been manually adjust for better relationships of these variables within the interest reservoir interval. The colour scale of these cross plots was based on the true vertical depth (TVD) from the seismic reference datum (SRD).

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Statistical and well group wavelets have been tested and compared to determine which is the best wavelet to reduce the uncertainty during the inversion process. Its impact on the inversion results also been examined in this research. The study was repeating with 50 iterations on the logs of inverting the synthetic using a constant value of $\gamma = 0.5$ due to lower root mean square (RMS) error as supported by Hampson's research [6].

Table 1 is the summary of inversion results which compare both well and statistical group wavelets for respective wells and the combination of three wells. We can conclude that inversion by using statistical group wavelet is more realistic and applicable for reservoir characterization. Besides, log correlation factor play more significant role than the RMS error between original and inverted well logs for inversion process.

Well	Group	RMS Error				Correlation	Error
	Wavelets	Zp	Zs	Density	Vp/Vs		
SU-1	Well	481.655	239.237	0.171	0.160	0.984	0.179
	Statistical	502.828	251.595	0.174	0.163	0.978	0.205
SEL-1	Well	234.16	164.06	0.06	0.170	0.987	0.165
	Statistical	436.28	220.93	0.103	0.188	0.984	0.178
UJ-1	Well	329.712	245.873	0.094	0.120	0.977	0.218
	Statistical	227.392	170.484	0.066	0.093	0.964	0.266
SU-1, SEL-1,	Well	294.304	333.342	0.122	0.152	0.636	0.772
UJ-1	Statistical	664.945	351.088	0.170	0.180	0.982	0.188

Table 1. Resulting error in the inversion curves for different group wavelets

3.3 Elastic Properties Analysis

Inversion process was applied to the whole seismic volume for modelling with the input of angle gathers, well logs, horizons, wavelets, as well as the initial models. Models with inverted elastic properties such as P-impedance, S-impedance, density, Vp/Vs and Lambda-mu-rho (LMR) between the target window of top reservoir to base reservoir were built. These models have a better image with clearer and details layering that allow us to easily differentiate the lithology and fluid present in our target reservoir.

These inverted results from each well were combined and few data slices created at the window

targeted on top reservoir at a fixed window size of 40 ms. This allows interpreter to characterize the reservoir by using a base map with elastic properties as the reference parameters.

Figure 7 is the inversion result for the control well SEL-1 where arrows indicating the hydrocarbon zone. The arrow in red indicate the gas sand zone, while the green arrows refer to oil sand layers. From the figure, we can identify the gas oil contact from well SEL-1 due to the sudden change of elastic properties such as acoustic impedance, Vp/Vs, density and Lambda-rho from gas sand to oil sand. This proves the study can resolve the problem stated in [1] that the fluid contacts were not seen in most wells of X field. Besides that, we can also identify thin shale that lying in between the hydrocarbon sand by using the inverted elastic properties.



Figure 7. Inversion models of well SEL-1(a) Inverted AI (b) Inverted SI (c) Inverted Rho (d) Inverted Vp/Vs (e) Lambda-rho (f) Mu-rho

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Figure 8. Data slice at top reservoir with window size of 40ms (a) Inverted P-impedance (b) Inverted Vp/Vs (c) Lambda-rho (d) Mu-rho

The inversion results for respective wells were then combined to generate few maps based on the distribution of elastic rock properties as inverted P-impedance, such inverted Vp/Vs, and Lambda-Mu rho across the survey area (figure 8). From these base maps, we can conclude that the area around well UJ-1, TE-1, SEL-1 and TEN-1 which gives low to medium acoustic impedance, low Vp/Vs, low λp , and low to high value of updue to presence of silty sand are indicating the region of interest in X Field.

4. Conclusions

In conclusion, this research successfully achieved the objectives and solved the problems with the inability to detect fluid contacts in most wells and to differentiate reservoir and non-reservoir lithologies from previous study. In this research, the gas oil contact was

detected in well SEL-1 due to the viable contrast in elastic properties between gas sand layer and oil sand layer as shown in Figure 7. We also presented that statistical group wavelet and vertical well are yielding a better inversion result for lithology and fluid discrimination as summarized in Table 1. Besides, provided with current availability data and software, the application of simultaneous inversion and its innovative approach Lambda-Mu rho (LMR) have been demonstrated in this research that these methods are powerful tools in predicting the lithology and fluid distribution in "X" Field of Sabah basin for better reservoir characterization as supporting from the results shown in Figure 8. This finding was further supported by the research done by [8] and [9]. Their research proved that the resolution of simultaneous inversion allows them to characterize the reservoir better compared to the post-stack inversion.

5. Future Study

It is recommended to further extend this study to Elastic Impedance Inversion (EEI) in the future as it is more advance and most closely related to the reservoir properties. It will describe better for our seismic cube as it is generally sensitive to both fluid types and porosity. It is also better if the reservoirs can be characterized by using the improvement method to Goodway's and comparing these two approaches to conclude which method will be the best for modelling the reservoir in my study area. Besides, correction to deviated wells should be done before conducting the inversion as the anisotropy effect will affect the quality of inversion results. IOP Conf. Series: Earth and Environmental Science **88** (2017) 012022

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