PROCEEDINGS
JOINT CONVENTION BANDUNG (JCB) 2021
November 23rd – 25th 2021

Evaluating Potential Reservoirs in the Gumai Formation at West Air Komering Area with Multi-Inversions Method

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Abstract
The Gumai Formation is often regarded as a regional seal to the prolific Baturaja and Talang Akar Formations. However, new discoveries were found in the Gumai Formation that makes it an interesting intra-field exploration target. Therefore, this paper aims to compare the result of seismic inversion methods, their effects on the distribution of lithology and porosity within the Gumai Formation in West Air Komering Area and see how they impact the prospectivity evaluation in the later stage.

The principle of seismic inversion is to transform seismic reflection amplitudes into impedance values that can be used as a guidance to distribute porosity, lithology, and fluid saturation. However, different inversion methods may induce non-unique AI results, especially when dealing with low-contrasts lithologies within the Gumai Formation. Therefore, a comparative study between several inversion methods is necessary to cross correlate between the results. Several deterministic inversion methods were chosen comprises Model-Based Inversion (MBI), Fast Track "Colored" Inversion (CI), and Linier Programming Sparse-Spike (LPSS) Inversion. The inversion results were then calibrated with the well data and subsequently used as input to the 3D static model to evaluate possible in-place volumes estimates after.

Results from LPSS and MBI shows many similarities whilst CI produced different result particularly in the southwestern part of the studied area. Despite many similarities, LPSS shows a blockier impedance compared to MBI. Overall, a high impedance anomaly in all inversion results indicates shaly sandstones. In general, the accumulation of shaly sandstones and relatively high porosity are observed in northeastern part of this area. There is a quite large range between the calculated volumetrics when each inversion result was used as input for the 3D property modelling.

This paper demonstrates a multi-scenario geophysical approach in evaluating intra-field potential which applicable to similar fields. By using multi-scenario method, risks and interpretation uncertainties are well captured. This will enable a better investment decision that also comply with the latest regulations from Indonesian Government.

Introduction
West Air Komering area is located in the southern part of the South Sumatera basin as one of Indonesia's most prolific hydrocarbon-bearing basins. The main hydrocarbon discoveries in the South Sumatera basin are concentrated in Talangakar and Baturaja formations. However, with the recent exploration activities, new discoveries in both stratigraphical and structural traps in the Gumai formation were found, making it an interesting intra-field exploration target.

Gumai formation consists predominantly of shales with intercalated sandstones. A multi-sequence stratigraphy was identified within the Gumai formation from the seismic and well logs data. Three seismic inversion methods were applied, which are Model-Based Inversion (MBI), Fast-track "Colored" Inversion, and Linear Programming Sparse-Spike Inversion. In the later stage, reservoir modelling was performed by incorporating well log analyses and seismic interpretation results into petrophysical and facies models. This paper demonstrates how seismic inversion methods affecting potential evaluation in shaly sand reservoir, which is applicable to similar fields.

Data and Method
This study was using the data from 3 wells and a 3D seismic cube covering an area of 52.8 km^2. Petrophysical analyses were conducted to produce porosity and lithology logs that are crucial for evaluating potential reservoirs. Furthermore, integrated geological and geophysical investigations were performed by assessing well log data, well correlations, and seismic characteristics to provide a structural and stratigraphic framework.

After having a better understanding of the study area and the correlation between acoustic impedance with other physical properties, several deterministic seismic inversions were carried out. Seismic inversion has been widely used in the petroleum industry for subsurface geological inferences (e.g., lithology, porosity) based on seismic analysis tied to well logs (Das, 2016). The most basic and commonly used one-dimensional model for the seismic trace is referred to as the convolutional model, which states that the seismic trace S(t) is simply the convolution of the earth's reflectivity RC(t) with a seismic source function W(t) with the addition of a noise component N(t) (Russel, 1988) as shown below:

$$S(t) = RC(t) * W(t) + N(t)$$

The acoustic impedance (AI) at the n^{th} layer can be expressed as:

$$AI_{(n+1)} = AI_{(n)} \frac{1 + RC_{(n)}}{1 - RC_{(n)}}$$

One of the most commonly used deterministic inversion methods is model-based inversion. This is an interesting method since it updates the model rather than the seismic data itself in the inversion process. First, the acoustic impedance model is built using well data with the seismic horizons guide and then compared with seismic data. Subsequently, the comparison results are used to iteratively updates the model to better match the seismic data. Once the process is finished, the model should become a cube containing absolute impedance values. This process was done by generalized linear inversion (GLI), which will derive a model that fits well with seismic in the least-squares sense.

Another method, Linear Programming Sparse-Spike inversion, points out that if high-resolution deconvolution is applied to seismic data, the reflectivity estimation will only be accurate in band-limited seismic frequency (missing high & low-frequency content). Recovering the missing frequency is considered a problem of non-uniqueness because of the infinite pairs of velocity and depth that will give in the same time value. Therefore, the layered geological model / blocky impedance model is added as a constraint in the form of a sparse-spike reflectivity function. This can be achieved by using the L1 norm algorithm as the sum of the seismic trace's absolute values that are minimized (frequency domain constraint) to generate a reliable frequency band and sparse reflectivity.

Finally, there is the fast-track “coloured” inversion method based on empirical studies that unconstrained sparse-spike inversion can be approximately modelled as a convolutional process, with an operator whose amplitude spectrum maps the mean seismic spectrum to the mean earth AI spectrum and has a phase of -90^o (Lancaster & Whitcombe, 2000). To perform this inversion method, design the linear trend operator in the frequency domain as a “desired output” shown on a log/log scale using AI log from well(s). Apply inverse fast-Fourier transform to have the operator in the time domain, then convolve it to the seismic cube. Just like sparse-spike inversion, the result of fast-track “coloured” inversion is relative impedance. If needed, add the low-frequency AI model to relative impedance to have the absolute impedance.

Each inversion method has its own unique nature based on its processes and algorithm. By comparing them, we can have a comprehensive and quantitative analysis of our area of interest and see the major trend resulted from all inversion methods. All of the results from the inversion method explained above will be used as inputs to build reservoir models.

Result and Discussion

In most cases, a hydrocarbon reservoir is associated with a low acoustic impedance anomaly since it often has the same lithology as the surrounding area. In this case, the sandstone reservoir is surrounded by shale stone. Sandstone has more compact characteristics than shale stone, making it have a greater acoustic impedance value than shale stone. This phenomenon was confirmed by the cross-plot analysis between AI and GR logs.

Model-based inversion method result shows a relatively high impedance anomaly in the north-eastern area. This method gives a good resolution result, but sometimes, it can be too dependent on the initial guess / low-frequency acoustic impedance model. Linear programming sparse-spike creates a broad-band, high-frequency result but without very thin layers often created by model-based inversion method. Therefore, it is shown as a blockier impedance model compared to model-based inversion. The method also shows a relatively high impedance anomaly in the north-eastern area. Meanwhile, fast-track “coloured” inversion produced different results, especially in the southwestern area. This method is directly linked to seismic data, simple, fast, and robust. Consequently, it is considered imprecise compared to other methods.

The differences happened because of the nature of each method. Model-based inversion, as the name suggests, is highly dependent on the low-frequency model. Linear programming sparse-spike only considered large spike (Poisson-Gaussian series), whilst the background spike (Gaussian series) is ignored. Fast-tack “coloured” inversion is the only method presented in this paper that did not use wavelet anywhere in the processes.

From all of the inversion results, the shaly sandstone reservoir and relatively high porosity associated with high impedance anomaly are located in the north-eastern part of this area. Based on paleontological study, the early Miocene Gumai formation is deposited in the marine environment at inner to middle neritic (Yuliansyah et al., 2014). It has the possibility of sandstone presence in the transgression period. Looking at the geometry of the reservoir guided with a gross depositional environment map, it is interpreted as having formed in a delta-front environment.

All inversion results are used as inputs for reservoir models resulted in a wide range of stock tank oil initially in-place (STOIIP) values. For comparison, considered fast-track ”coloured” inversion result as a baseline, the differences in STOIIP calculation values are 11% and 51% for linear programming sparse-spike and model-based inversion, respectively.

Conclusions

- Each deterministic inversion method has its own distinct characteristics. Therefore, differences in the results between each method are expected to some extent.

- Based on seismic inversions analyses using Model-based, Linear Programing Sparse-spike, and Fast-track “Colored” inversion methods show us the distribution of relatively high impedance anomaly and interpreted as a sand reservoir having formed in a delta-front environment.

- A wide range of stock tank initially in-place values are identified by incorporating seismic inversion result in reservoir model creation.

References

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Acknowledgements
The authors would like to thank Geophysical Engineering Department of Universitas Pertamina for supporting this research, Tiarabumi Petroleum for permission to publish this research, and Rock Flow Dynamics for facilitating the tNavigator software.

Appendix

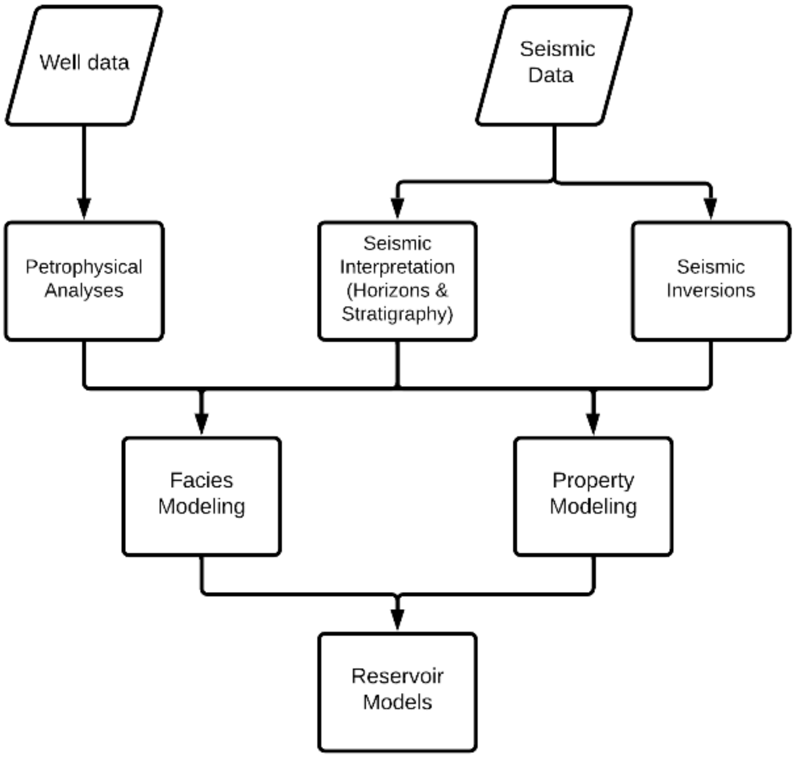

Figure 1: Workflow of the study

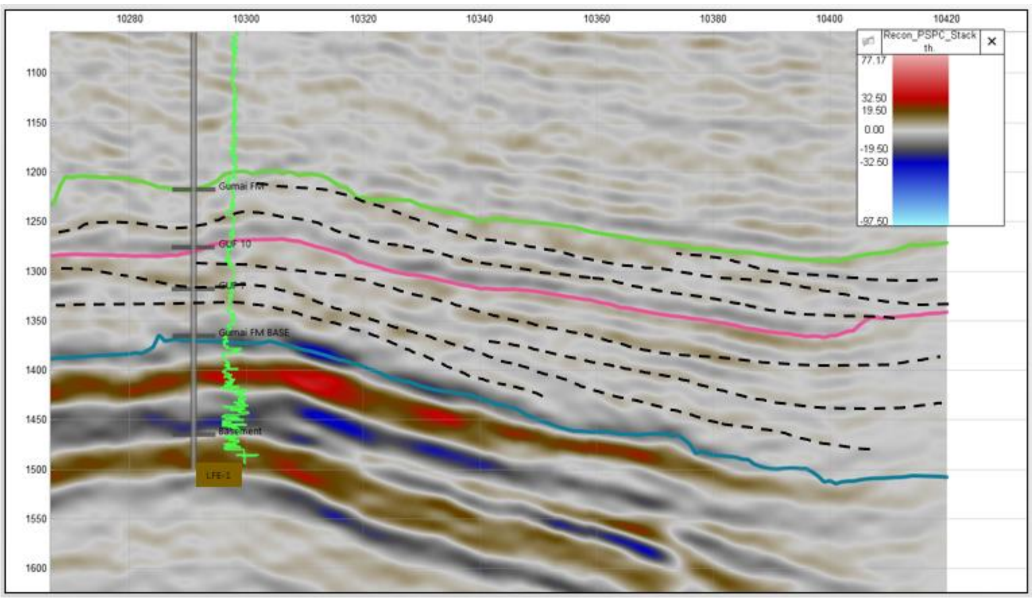

Figure 2: Seismic stratigraphy of Gumai formation showing two different sequences within the formation

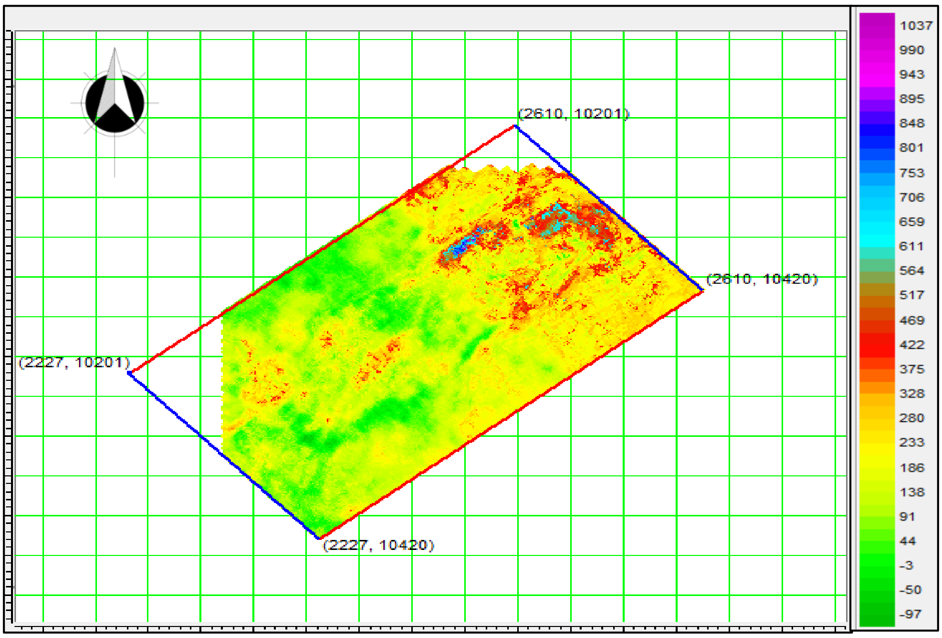

Figure 3: Horizon slice showing average amplitude of relative impedance value from Model-based Inversion

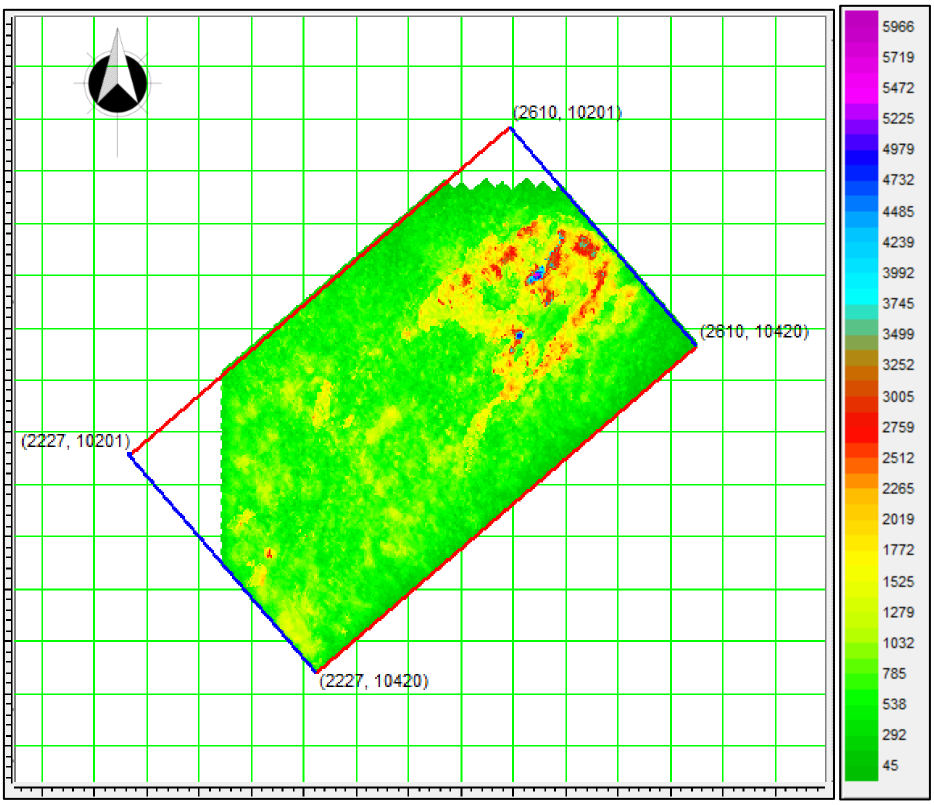

Figure 4: Horizon slice showing average amplitude of relative impedance value from Linear Programming Sparse-spike Inversion

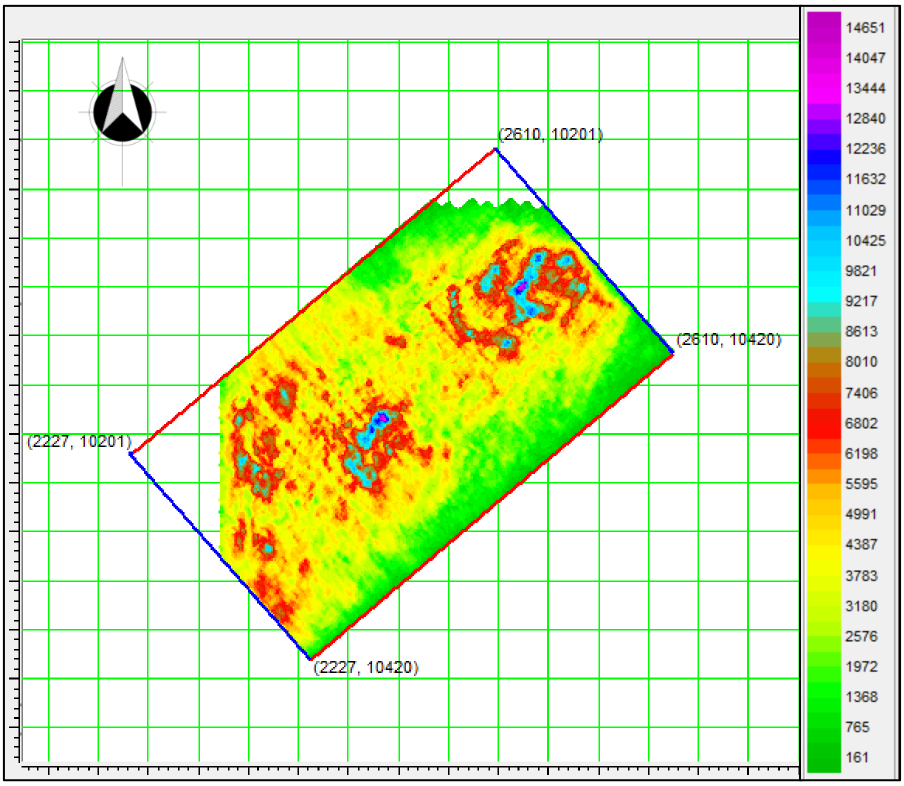

Figure 5: Horizon slice showing average amplitude of relative impedance value from Fast-track "Coloured" Inversion

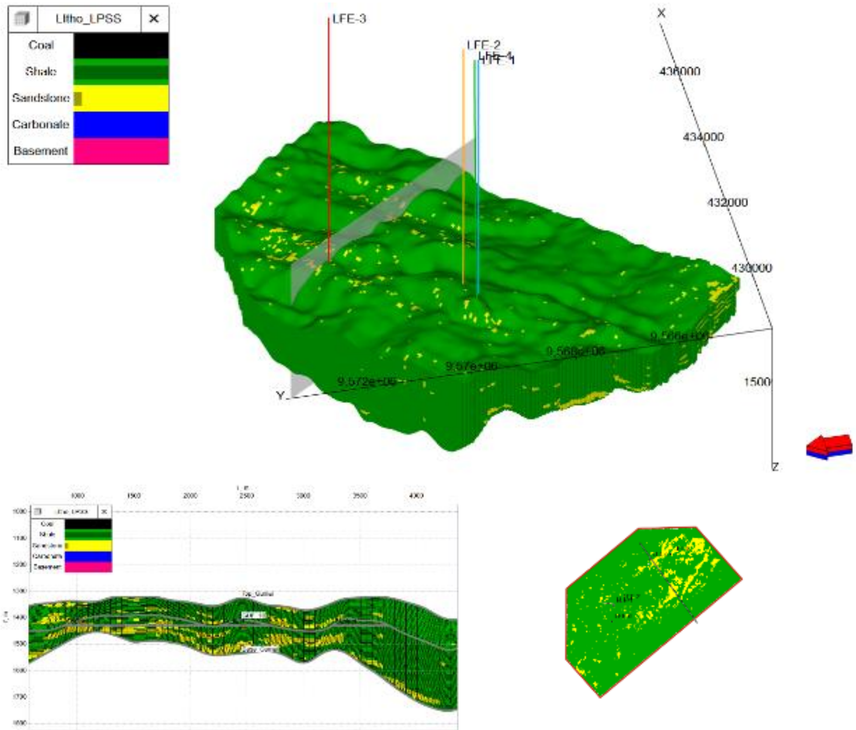

Figure 6: An example of facies model using seismic inversion result.

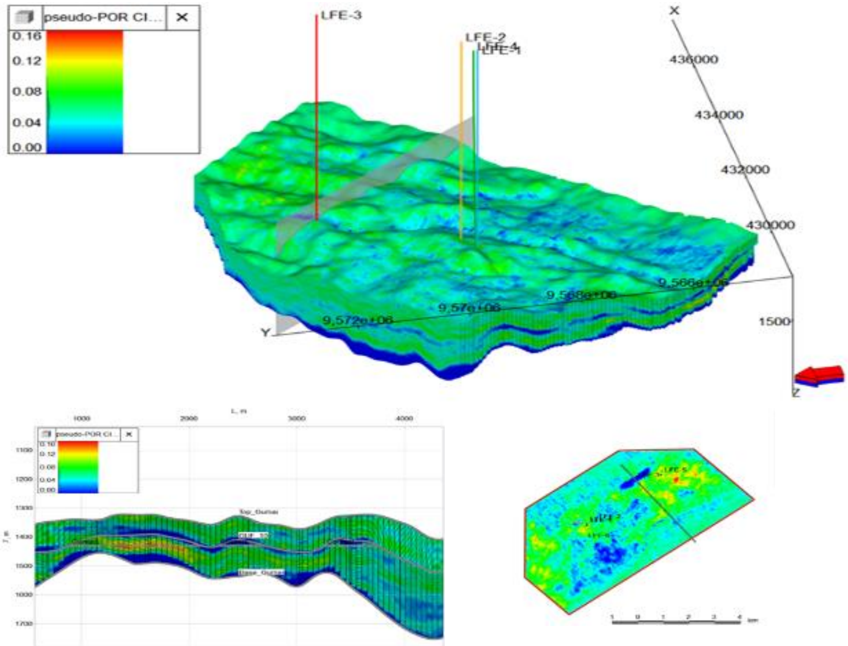

Figure 7: An example of porosity model using seismic inversion result.