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Stochastic Inversion in Determining the Distribution of Petroleum Carrying Sandstones in the "JS" Field of the South Sumatra Basin

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Abstract

The "JS" field is a field located in the South Sumatra Basin, where the field has good prospects for the distribution of petroleum-bearing sandstone. The target of this research is the Air Benakat formation. This research uses the stochastic seismic inversion method to determine the probability of finding petroleum in sandstone. Stochastic seismic inversion has the advantage that it can overcome thin layers and can reduce existing data misalignments. So stochastic inversion can overcome the shortcomings of other seismic inversions, especially model-based seismic inversion which is the initial model for stochastic seismic inversion. Stochastic seismic inversion produces several realizations by showing uncertainty so as to get results that are close to the actual situation. Probability map of oil-bearing sandstones located in the north and east of the study area. with the slice results obtained for the acoustic impedance range of 8517-9051(m/s)*(g/cc) and oil sand probability with a value range of 0.61-0.78%.

Keywords: Petroleum; South Sumatra Basin; Stochastic Inversion.

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Introduction

The "JS" field in this research is in the South Sumatra basin, where the South Sumatra basin is one of the back arc basins that has hydrocarbon potential in Indonesia. One of the formations in the South Sumatra Basin that produces hydrocarbons in the form of oil is the air bekanat formation. The basin is bounded by the mountain range in the southwest and the Sunda Shelf in the northeast. This basin has been proven to produce hydrocarbons with types of hydrocarbon traps that develop in the form of structural traps, stratigraphic traps, and a combination of the two traps (Prasetiyohadi et al., 2022).

The South Sumatra Basin is one of the basins that was formed because of tectonic movement between the Indo-Australia plate and Eurasia. The South Sumatra Basin began to form during the extension between the two plates which trended East-West at the end of the Pre-Tertiary – early Tertiary. Geologically, this basin is a foreland basin or back arc basin type (Gahana et al., 2019).

Stratigraphy

South Sumatra Basin is a basin where geological structures play a very active role in sediment deposition, good geological structures that occur during phases pre-rift, syn-rift, and post-rift (Gaol, 2016).

According to Rahmadani et al. (2020), structural development and basin evolution since the Tertiary are the result of the interaction of the three main structural directions (Figure 1). These include, the northeast-southwest direction or called the Jambi Pattern, the northwest-southeast direction or called the Sumatra Pattern, and the north-south direction or called the Sunda Pattern. This is what makes the geological structure in the South Sumatra Basin area more complex than other basins on the island of Sumatra. The northeast-southwest trending geological structure or Jambi Pattern is very clearly observed in the Jambi Sub-Basin.

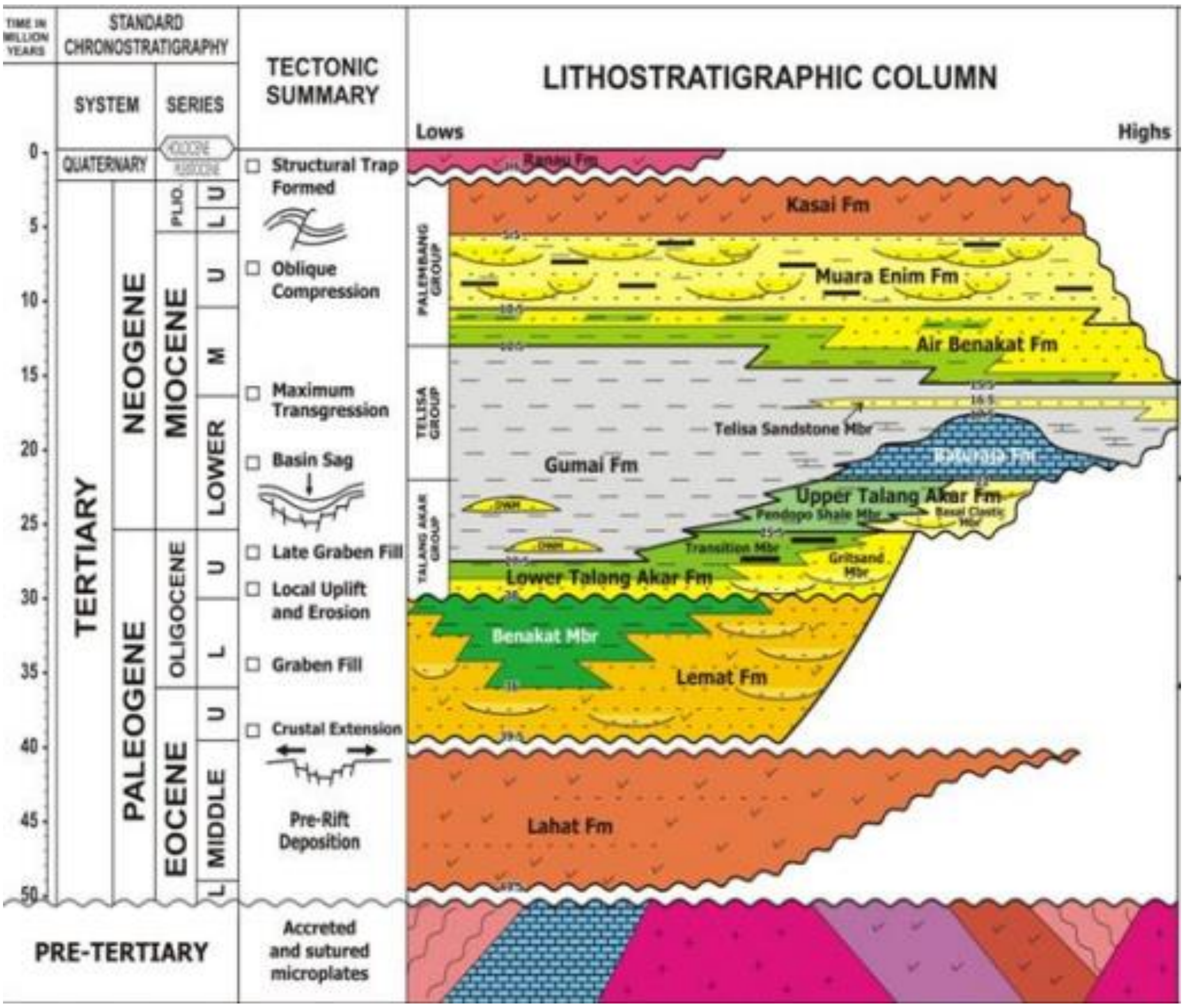

Figure 1. Stratigraphy of the South Sumatra Basin (Lukman et al., 2019).

Seismic Reflection

Seismic reflection is one of the geophysical methods used in exploration, especially hydrocarbons, using elastic waves as an interpretation medium. In principle, this method uses reflection principle from source to receiver. Seismic waves carry information about lithology and subsurface fluids in the form of travel time, reflection amplitude and phase variations (Dani & Sule, 2021). Supported by developments in computerized technology, seismic data processing, as well as interpretation techniques, seismic data in can be analyzed to delineate the physical (acoustic) properties of rocks and determine lithology, porosity, pore fluid, and so on.

Seismic Inversion

Seismic inversion is a technique for creating subsurface geological models using seismic data as input and well data as a control (Srivastava & Sen, 2009).

Seismic inversion serves as a crucial tool for estimating subsurface parameters in reservoir geophysics, playing a significant role in lithology prediction and geofluid discrimination. The seismic inversion method is one of method to describe and estimate the lower physical parameters surface in the form of acoustic impedance values using seismic data as input the data and well data as well the control. Acoustic impedance inversion is one of the seismic inversion methods after the stack (Prastika et al., 2018; Li et al., 2019). Deterministic inversion and stochastic inversion are inversion techniques that can be used. Deterministic inversion produces the inversion models with low frequency, so stochastic inversion is needed to reduce the problem of ambiguity and high uncertainty. So, it can find out the thin reservoir layer.

Stochastic Seismic

Stochastic seismic inversion is an inversion technique whose basic principle is to use a random simulation algorithm and produce more than one acoustic impedance model that meets the observed seismic data. More than one solution can overcome the problem of non-uniqueness and uncertainty in deterministic inversion, especially in the case of thin layers. (Fernandes et al., 2023). A stochastic inversion method is proposed for seismic reservoir characterization, aiming to provide models of facies and reservoir properties. This iterative optimization process is achieved through the probability perturbation method based on conditional simulation with multi-point geostatistics. Additionally, it incorporates a quantum annealing algorithm to enhance the accuracy of the inverted reservoir properties (Liu et al., 2018). Another advantage is that this method does not depend on the bandwidth of the seismic data used but on the block size when simulating the impedance model so that the results of this stochastic inversion are less smooth than the results of deterministic inversion. And by using this inversion you can capture small variables so that the resulting data is more accurate.

Materials and Methods

Data

The data source for this research comes from PT Pertamina Hulu Rokan Zone 1 which is located in Jambi City, Jambi. In its implementation, CGG HRS 10.6 and Petrel 2018 software were used. 3D Post Stack Migration (PSTM) seismic data was used and 3 wells data (Figure 2) with logs for each well were gamma ray, neutron porosity, density, caliper, resistivity, sonic, marker and checkshot (Table 1).

Table 1. Well data availability.

Log/well	J2	J5	J6
GR	√	√	√
NPHI	√	√	√
RHOB	√	√	√
PHIE	√		
DT	√	√	√
CALI	√	√	√
SP	√		√
Checkshot Marker	√	√	√

Data processing

Overall data processing is carried out on well data and seismic data. The number of well data used is 3, including; J1, J5, and J6, where a well sensitivity analysis will be carried out to determine the existence of the desired target. After obtaining the desired target, the well is tied to seismic so that there is alignment between the well target and the seismic data (Figure 3). Meanwhile, in processing seismic data, several stages are carried out, including horizons interpretation and faults to determine the continuity of the target layer so that the presence of the target is known in the seismic data, then doing time to depth to change the presence of the target from time domain to depth domain. After determining the presence of the target, a model-based seismic inversion was carried out (Figure 4) which became the initial model for stochastic seismic inversion and obtained cross sections resulting from the inversion that has been carried out so that the presence of sandstone containing petroleum can be analyzed based on the inversion impedance and porosity values.

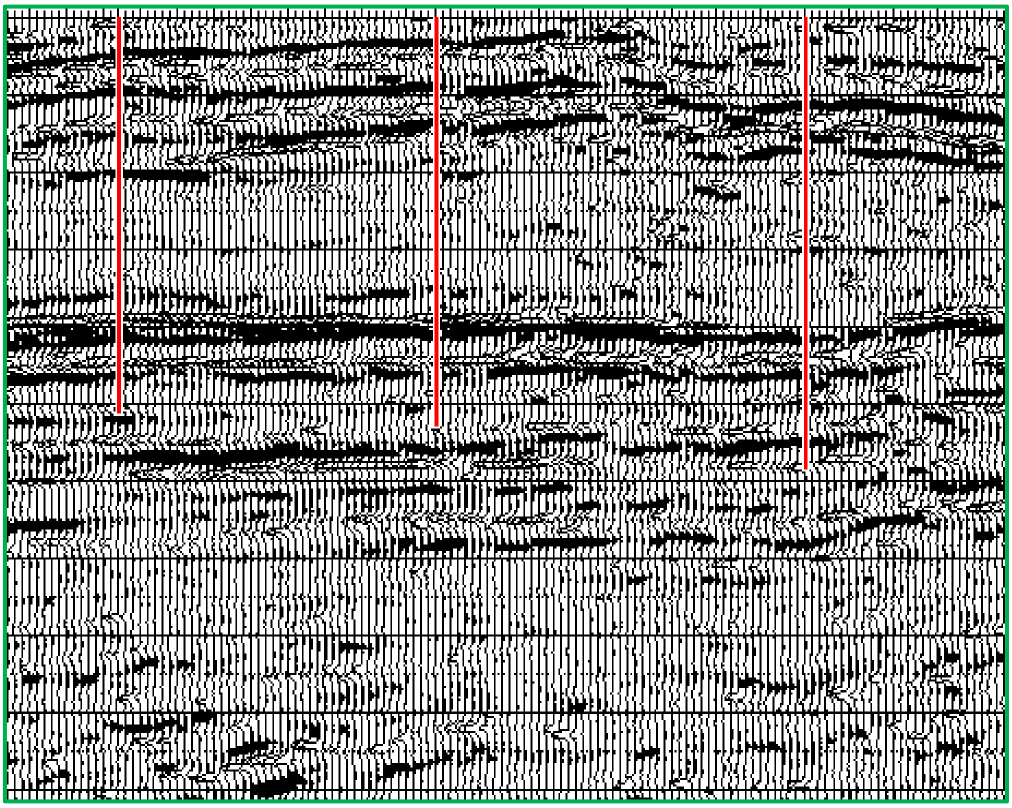

Figure 2. Seismic section of the "JS" field.

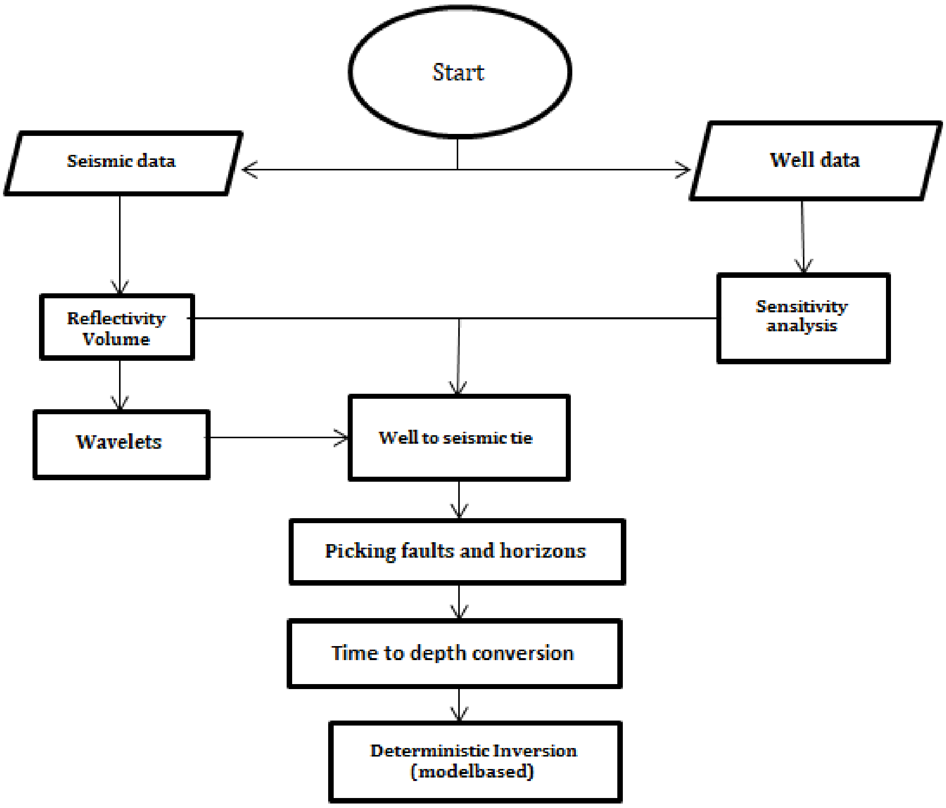

Figure 3. Model-based inversion flow diagram.

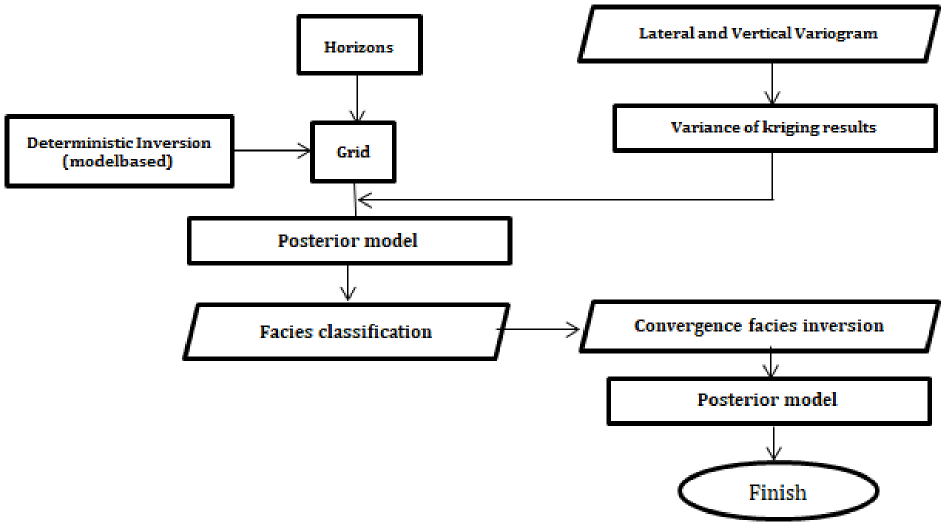

Figure 4. Stochastic inversion flowchart.

Results and Discussion

Wavelet Extraction

Wavelet extraction is very necessary in inversion which aims to equate synthetic seismogram and seismic data in well location (Dikman et al., 2015). Wavelets can be extracted by several methods such as statistical, bandpass, ricker, and usewell. Wavelet extraction in this research, trial and error was carried out to obtain the best. Based on synthetic seismogram analysis, ricker model generates the best model that has the similarity with the observed seismogram.

Well to Seismic Tie

This process aims to change the depth domain into a time domain for the well, so that well data can be linked to seismic data. So, the results of this process can determine the exact whereabouts of the marker data in the seismic data (Kumalasari et al., 2018; Liu et al., 2022). This process requires sonic log and density log data. In the well to seismic tie process, a stretching process is carried out with the aim of obtaining a high correlation, which is more than 0.5 or close to 1 with a time shift value close to 0.

Sensitivity Analysis

Sensitivity analysis can be carried out by carrying out a crossplot between log data to determine the sensitivity of the target well. Crosplots are carried out to separate and determine shale or nonshale lithology and determine the acoustic impedance susceptibility value of the target zone (Pradana et al., 2017; Xue & Mrinal, 2016). This research uses gamma ray logs, P-impedance logs, and porosity logs in lithological separation. Crossplot from well J2 (Figure 5) where the x-axis is a parameter of P-impedance and the y-axis is a parameter of porosity and color index using gamma ray logs. With the gamma ray log cut-off being at 95 API, where if an area with a value of less than 95 API is declared as sand, it is marked with a yellow area with a porosity value ranging from 0.05 – 0.15% and a P-impedance value ranging from 8000 – 9300 (m/s)*(g/cc), while areas with a value of more than 95 API are declared as shale which is marked with a green area with a porosity value ranging from 0.01 – 0.05% and a P-impedance value ranging from 6500 – 8200 (m/s)*(g/cc). And from the crossplot of well J2 there is lithology which is stated as non-shale which is marked by a brown area with a low gamma ray value, which is in the P-impendace value area of 7400 – 8000(m/s)*(g/cc) with porosity values range from 0.15 – 0.23.

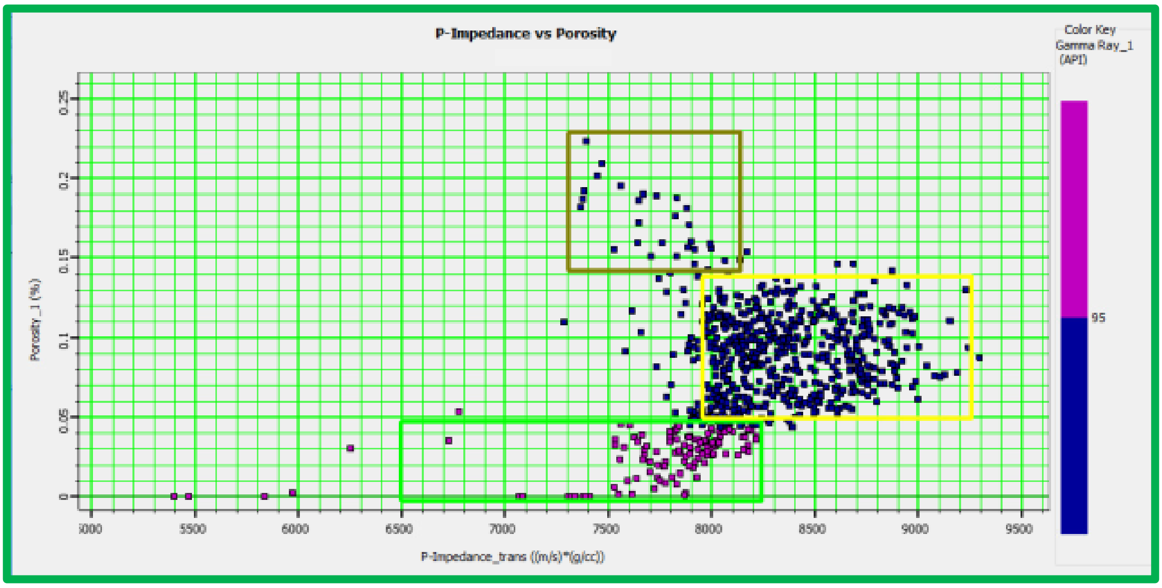

Figure 5. Crossplot well J2.

Fault and Horizon Interpretation

Horizon interpretation is useful in marking the continuity of each formation from a marker that has been well to seismic tied (Novriyani et al., 2016) (Figure 6). So, it can know the correlation between seismic data and well data. Meanwhile, fault interpretation is useful in indicating areas where faults occur in seismic data. So, it can help in determining the horizon in the continuity of the layer structure. In horizon interpretation, this research was carried out in the Otakat water formation.

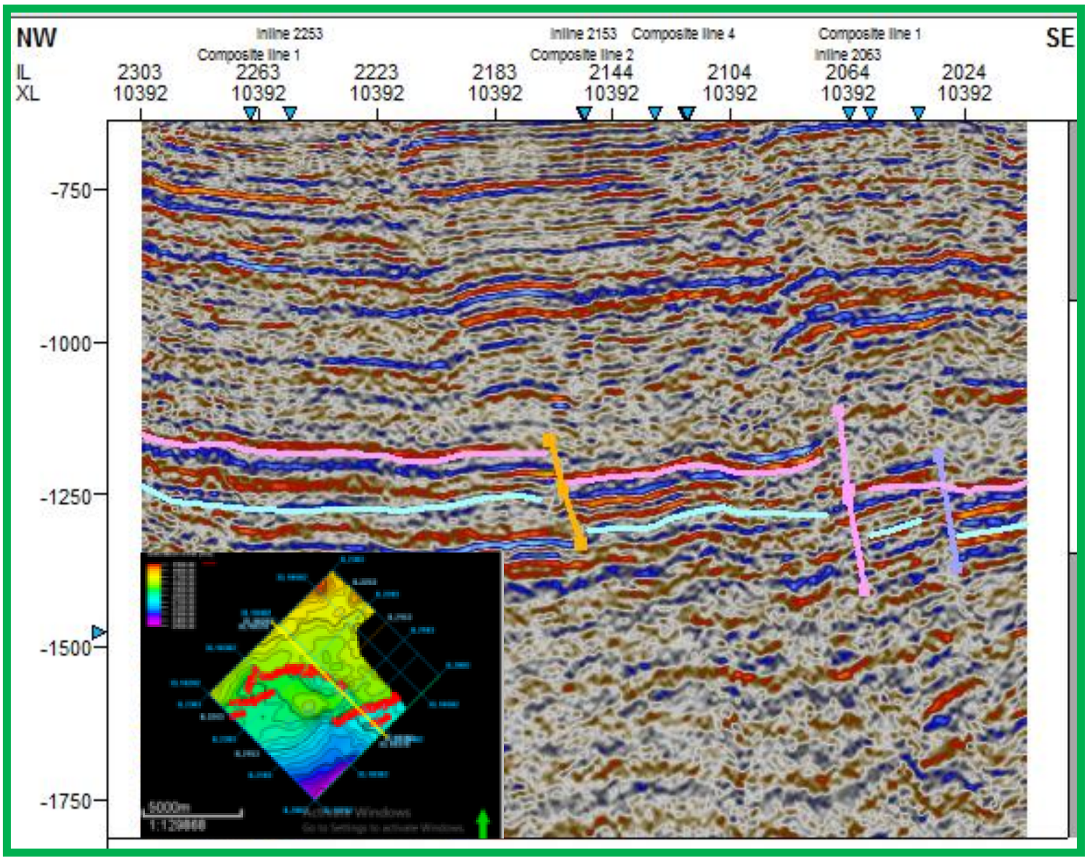

Figure 6. Fault and horizon interpretation.

Initial Model

Seismic inversion is defined as a technique for creating subsurface models using seismic data as input and well data as control. The initial model is the initial model used as a reference in the seismic inversion process (Irvanaya, 2022) (Figure 7). This model was created based on geological information and geophysical data available before the inversion process was carried out. In this study, an initial model was created using a 3D seismic section as input and 3 wells as binding, which are well J2, J5, and J6. This is where the initial model will be used in the process of creating the inversion model.

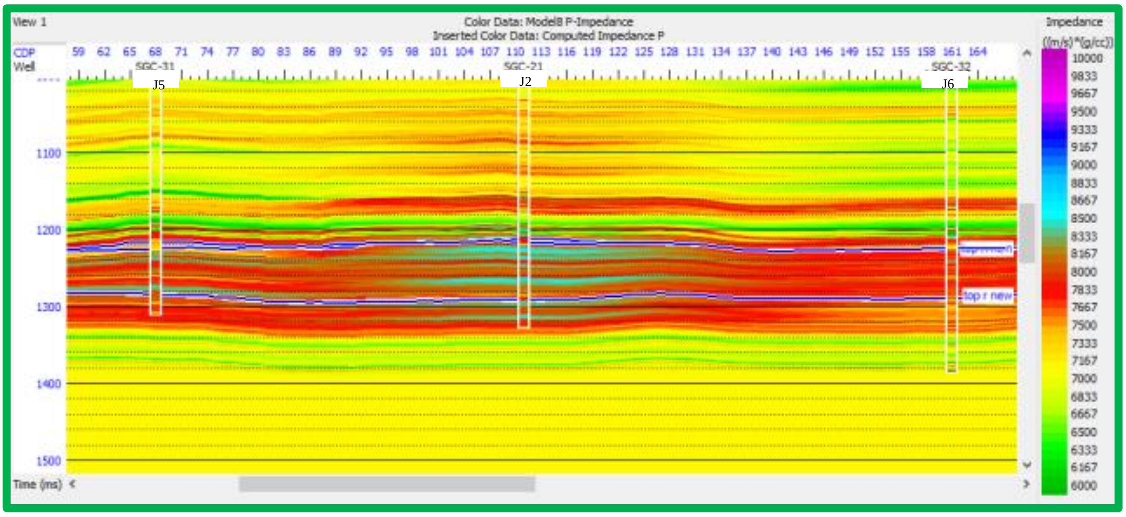

Figure 7. Cross-section of initial model.

Inversion Model-based

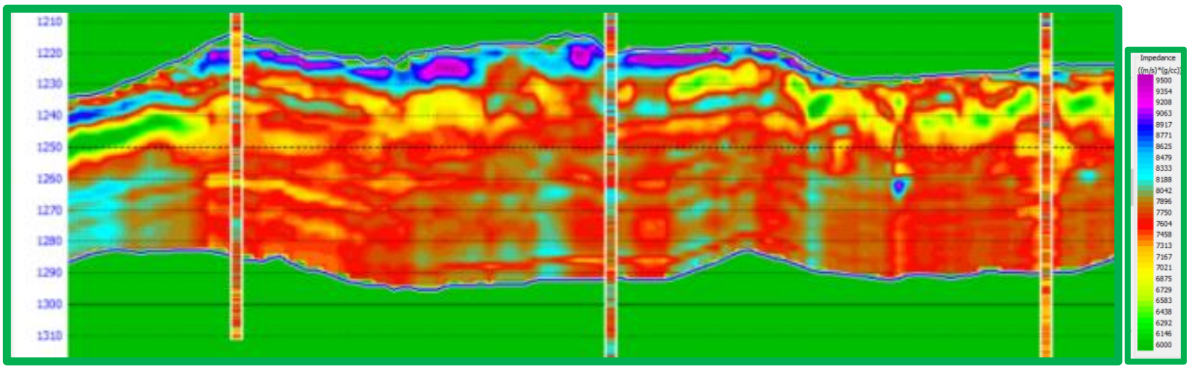

Figure 8. Model-based inversion cross-section.

This research uses model-based post stack deterministic inversion because in this model-based inversion process the modeling results almost resemble the actual geological cross-sectional shape (Figure 8). This method does not perform inversion of seismic data alone, but instead performs inversion of geological models based on well data control (Latifah et al., 2019). The model-based inversion method produces quite good results and is in accordance with the well data, However, the results still tend to be smooth and blocky, so they are not able to resolve thin layers well (Devi, 2018). This research uses data from wells J2, J5, and J6. The model-based cross section shows areas based on acoustic impedance values in the range 6000 – 10000 (m/s)*(g/cc). Areas that have low acoustic impedance value are interpreted in green. Meanwhile, areas that have high acoustic impedance values are interpreted in purple. Zones with high acoustic impedance values indicate denser sandstone reservoirs, while zones with lower acoustic impedance values indicate more porous sandstone reservoirs. This is because the acoustic impedance value resulting from the P wave velocity and density values describes the nature of the rock, where the P wave that propagates in the rock propagates into the rock matrix through which it passes.

Stochastic inversion

Stochastic seismic inversion is an inversion technique whose basic principle is to use a random simulation algorithm and produce more than one acoustic impedance model (Rashad et al., 2022). The number of realizations is determined based on the size of the data, the duration of the inversion process and the capabilities of the coarse equipment used. The greater the number of realizations will of course affect the statistical calculations, for example reducing uncertainty better (Rohaman, 2017).

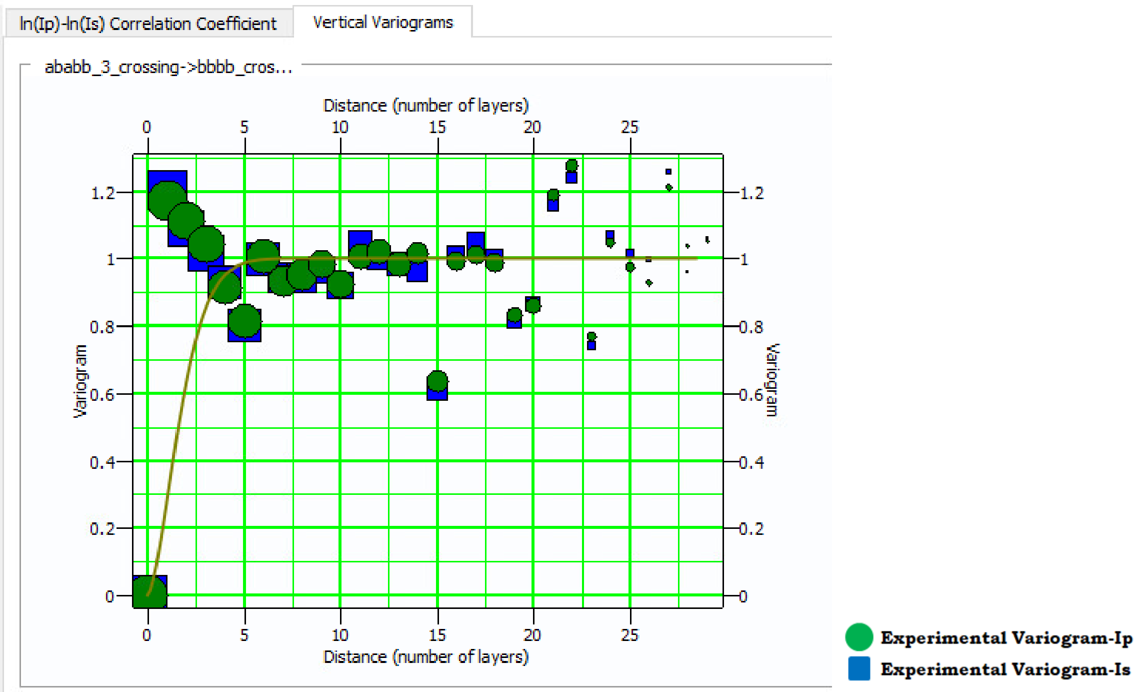

Figure 9. Stochastic inversion variogram.

Variogram analysis is carried out to show the spatial relationship between data in the inversion processstochastic seismic. The variogram analysis carried out is a horizontal variogram (Ekawati & Winardhi, 2018). In Figure 9, the variogram parameters of Ip and Is are used. The Ip value is marked in blue and the Is value is marked in green. At the existing variogram diagram, there is a dissimilarity between each parameter, so it is suspected that there is misalignment.

		Ip	Is	Ip	Is	Ip	Is	Ip	Is
Uncertainty	All Model	4.17 %	6.54 %	3.25 %	5.20 %	4.83 %	7.47 %	4.38 %	6.89 %
	ababb_3_crossing -> bbbb_crossing	4.17 %	6.54 %	3.25 %	5.20 %	4.83 %	7.47 %	4.38 %	6.89 %
Correlation Coefficient	All Model	0.99		0.99		1.00		0.99	
	ababb_3_crossing -> bbbb_crossing	0.99		0.99		1.00		0.99	
Number of samples	All Model	120	120	40	40	40	40	40	40
	ababb_3_crossing -> bbbb_crossing	120	120	40	40	40	40	40	40

Figure 10. Variogram value for each well.

From the values seen (Figure 10), 150 realizations can be seen from the approach taken from the realizations formed on the facies being classified. Where facies are shown on a line that rises from realization 1 to realization 150. From the existing calcification relationships there are values that rise and fall in the process of reducing the ambiguity of the existing facies (Figure 11). So, it get a dominant approach calculation value that is close to the existing facies value.

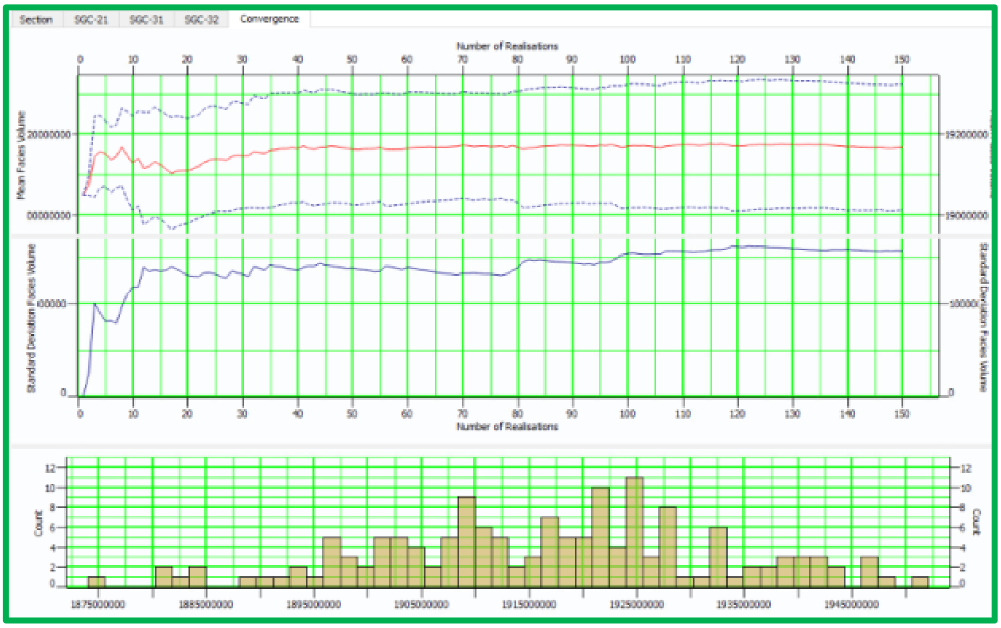

Figure 11. Realization relationships after facies calcification.

In the stochastic inversion seismic section at well J2, the impedance value ranges from 6000 – 10000 (m/s)*(g/cc) with the lowest value in green and the highest value in purple. At the cross-plot values for well J2 (Figure 12), the area marked as shale is at 6500 – 8200 (m/s)*(g/cc) with a light green to pink color range. And the area marked as sand is at impedance 8000 – 9300 (m/s)*(g/cc) with a color range of red to dark blue. So that this area can become a hydrocarbon prospect area. Areas with higher values indicate denser reservoir sand because the impedance value comes from multiplying the wave by density so that it can describe the nature of the rock layers.

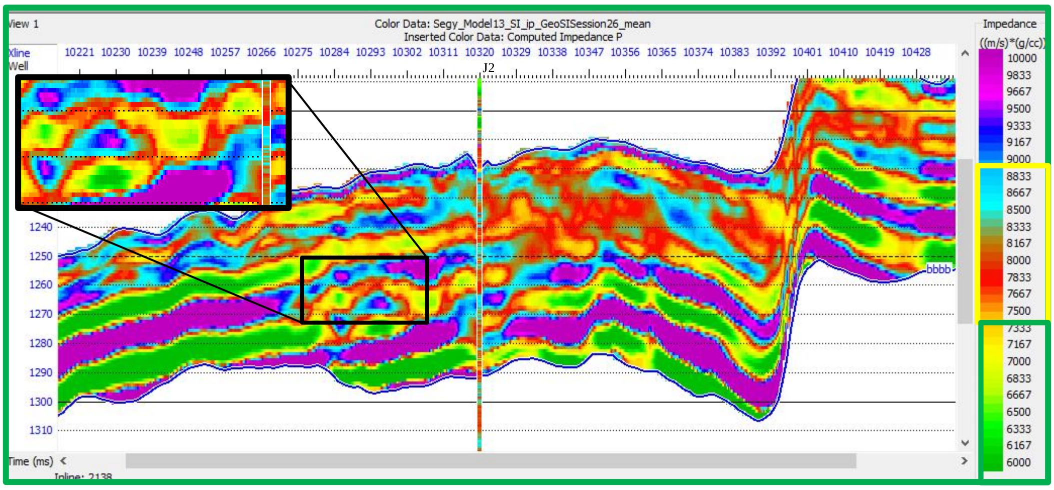

Figure 12. Stochastic inversion seismic section at well J2.

In the oil sand probability cross section (Figure 13), the probability range is from 0.04-0.9 with the lowest value being white while the highest value is purple. The probability value shows the possibility of an oil-bearing layer area. The value closer to 1 indicates that the layer is an oil-bearing area. So this area is included in the area of high hydrocarbon potential.

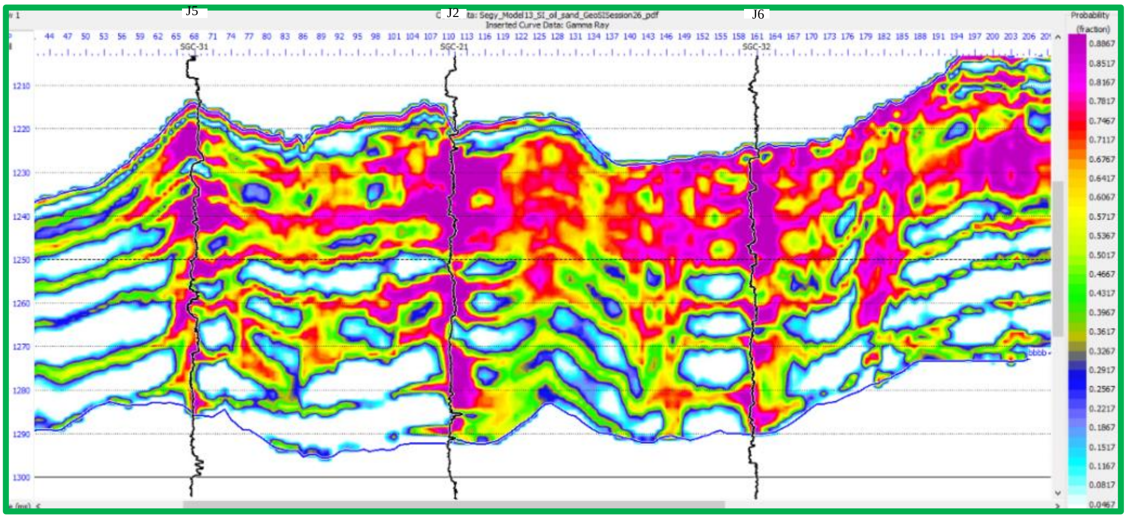

Figure 13. Cross-section based on oil sand probability.

Slice Results

Model-based inversion slices where the range of slices made is around 8,500 – 9,900 (m/s)*(g/cc) which is marked with the smallest value in green and the largest value is marked in purple. So, the results of this slice show that areas of denser sand are purple and areas of less dense sand are green (Figure 14). Because the higher the impendance value of a layer, it can be said that the layer is denser. And from the results of the model-based inversion slice, the hydrocarbon prospect cutoff value ranges from green to yellow.

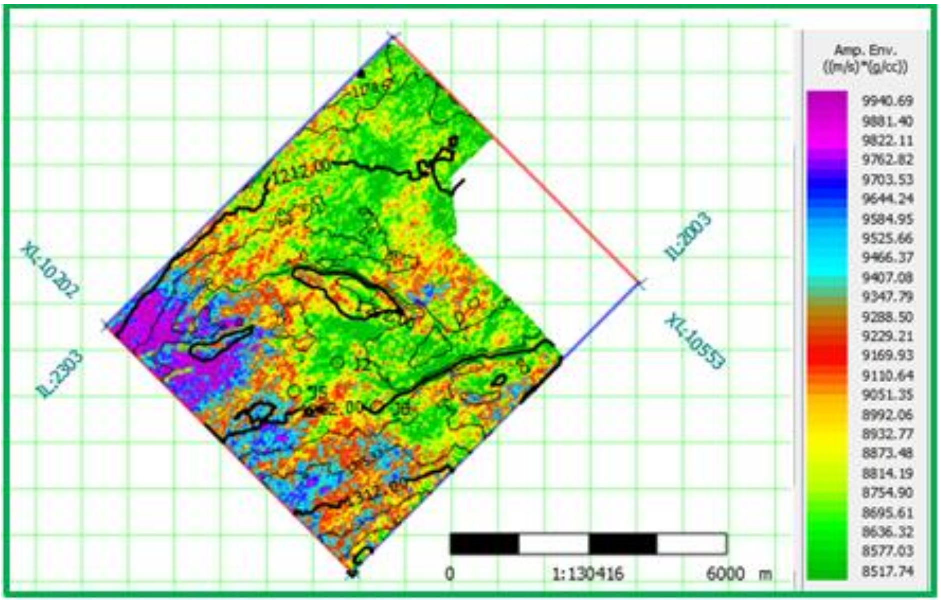

Figure 14. Model-based slice inversion.

Slice from stochastic inversion modeling of the Ip mean cross section which aims to determine the distribution of impendace values in the "JS" field (Figure 15). Based on the cross-plot analysis that has been carried out, the presence of sand has a value that tends to be high. The values in the slice results obtained impendace values ranging from 8517 – 9940 (m/s)*(g/cc) with the lowest value marked in green to the highest value marked in purple. Meanwhile, the crossplot value results that have been analyzed are around 8000 – 9000 (m/s)*(g/cc) and are marked on the slice results from green to reddish yellow.

The slice results show the areas where oil sands are located (Figure 16). So that the existence of hydrocarbon prospects is known. The range for the slice results is 0.19 – 0.78. where the higher the value of an area, it shows that the area has prospects for oil sands or hydrocarbons. Areas that are suspected to be hydrocarbon prospects are shown in red-purple areas.

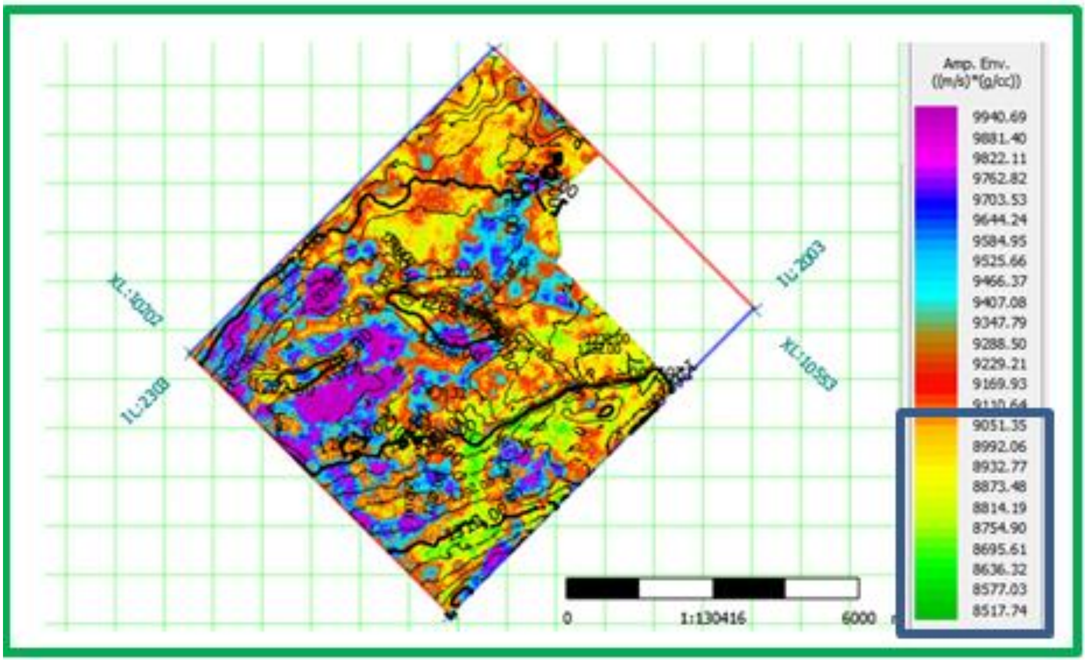

Figure 15. Stochastic inversion slice Ip mean.

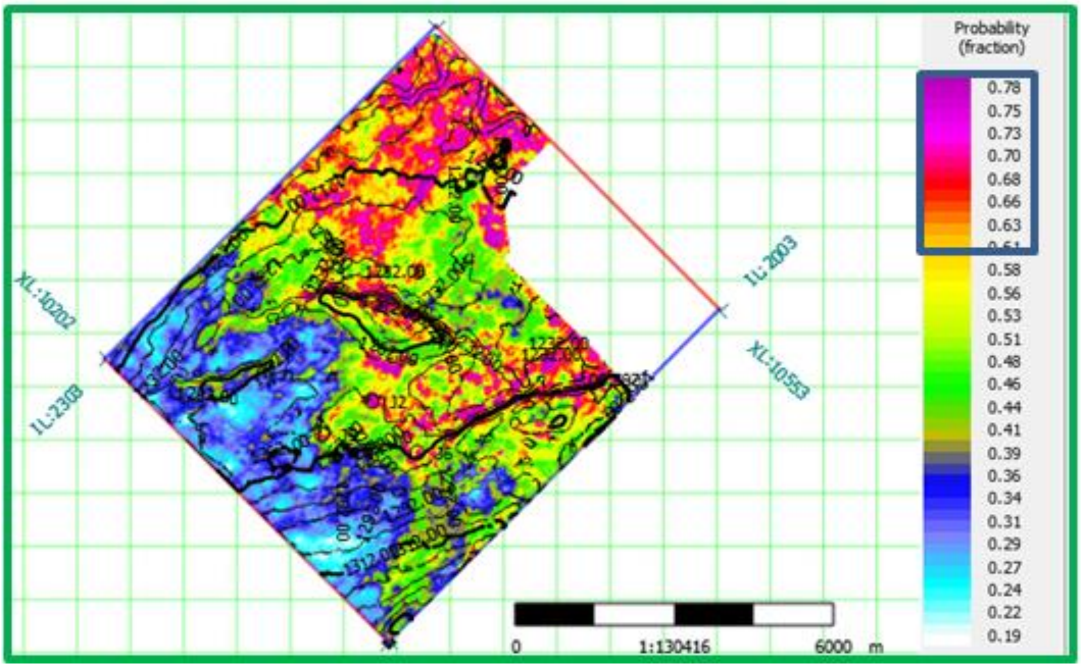

Figure 16. Stochastic inversion slice probability oil sand.

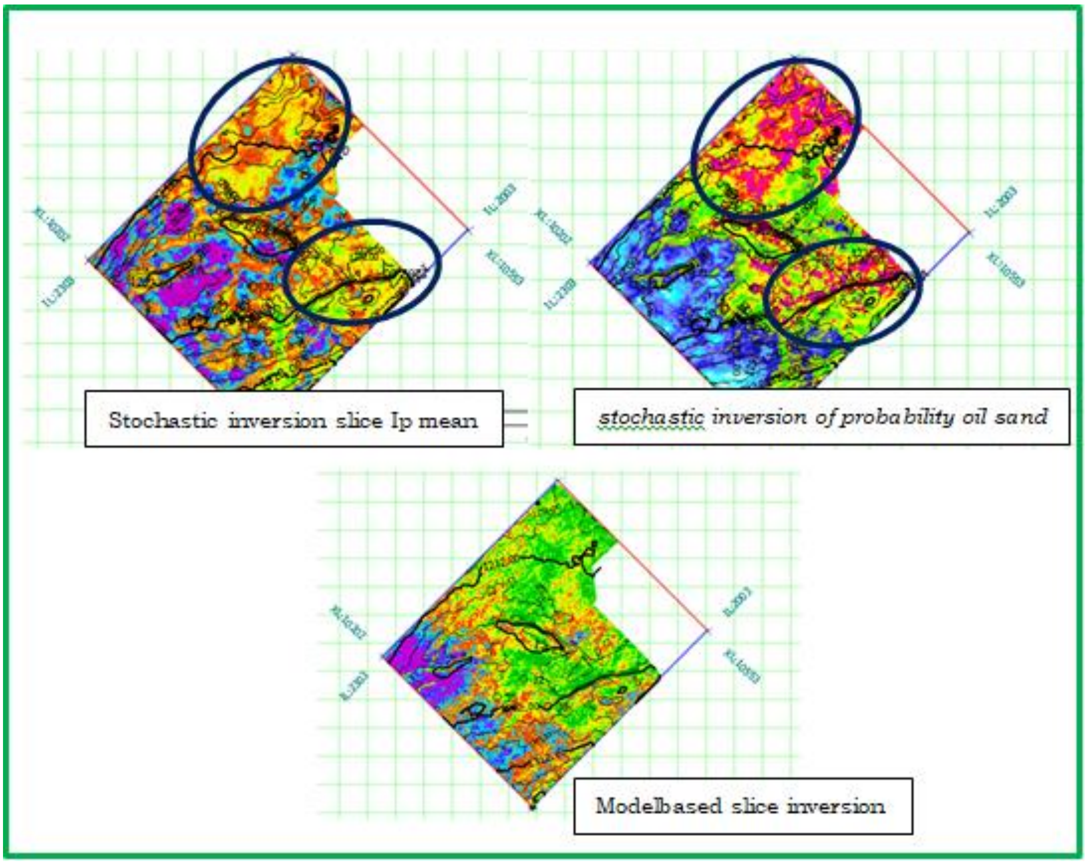

Figure 17. Comparison of slice results.

From the model-based slice with stochastics, the areas that have higher impendance are in the same area, but the results of the stochastic inversion slice show areas that are clearer regarding the existing distribution so that the results obtained are more accurate. If we compare the slice results from the stochastic inversion of Ip mean and the slice results from the stochastic inversion of probability oil sand, we get areas that have quite high hydrocarbon prospects. Where the area marked in Figure 17 is a sandstone distribution area with a vulnerable impendance value of 8000 – 9000 (m/s)*(g/cc) and for probability oil sand at 0.19 – 0.78.

Conclusion

Based on the research findings, the inversion of seismic data has yielded spatial uncertainty values for wells J2, J5, and J6. For well J2, the uncertainty values are (Ip) 3.25% and (Is) 5.20%. For J5, the values are (Ip) 4.83% and (Is) 7.47%. Meanwhile, for J6, the values are (Ip) 4.38% and (Is) 6.89%. Additionally, correlation coefficient values were calculated, with J2 having a coefficient of 0.99, J5 having a coefficient of 1.00, and J6 having a coefficient of 0.99. In the "JS" field, the hydrocarbon zone is identified within the acoustic impedance slice results ranging from 8517 to 9051 (m/s)*(g/cc). Furthermore, the probability values for oil sand in this zone range from 0.61 to 0.78.

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Author Contribution

This paper was completed thanks to the cooperation of all authors. The idea for

this topic was first put forward by Juventa. Data processing and interpretation was carried out by Johannes Kurni Bintang Awan Situmorang who was supervised by Muhammad Suhban and Ghindo Tampubolon helped arrange the background and some editing. Hopefully this kind of collaboration can continue.

Conflict of Interest

No potential conflicts of interest were reported by the authors. This research was entirely carried out by the author under the guidance of the author's lecturer.

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