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Application of the Acoustic Impedance (AI) Seismic Inversion and Multi-Attribute Method for Reservoir Characterization in Bonaparte Basin

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Abstrak. Penelitian mengenai penerapan metode seismik inversi *acoustic impedance* (AI) dan *multi-attribute* telah dilakukan dengan tujuan untuk karakterisasi reservoir pada Cekungan *Bonaparte*. Pemodelan yang digunakan dalam metode seismik inversi *acoustic impedance* berupa *model based.* Sedangkan pada metode seismik *multi-attribute* menggunakan log porositas dengan menerapkan metode regresi linear serta menggunakan teknik *step-wise regression*. Berdasarkan hasil analisis sensitivitas dan analisis dengan metode seismik inversi *acoustic impedance*, zona reservoir dengan litologi batu pasir yang prospek akan hidrokarbon dan mengandung gas berada pada bagian Timur Laut - Barat Daya pada daerah penelitian yang berada di WCB-1, WCB-3 dan WCB-4 dengan rentang nilai *acoustic impedance* sebesar 4.800–13.000 (m/s)*(g/cc), dan nilai porositas yang dihasilkan dari analisis menggunakan metode seismik *multi-attribute* berada pada rentang 5–16% pada WCB-1 dan WCB-4, 2–10% pada WCB-3.

Kata Kunci: *acoustic impedance*, *multi-attribute*, *model based*, *step-wise regression*.

Abstract. Research on the application of the acoustic impedance (AI) seismic inversion and multi-attribute method was conducted with the aim to characterize the reservoir in the Bonaparte Basin. Model-based is the modeling that is used in the acoustic impedance of the inversion seismic method. Meanwhile, log porosity is used in the multi-attribute seismic method that using the linear regression method with stepwise regression technique. Based on the result of sensitivity analysis between acoustic impedance, the reservoir zone in sandstone lithology that has the prospect of hydrocarbons containing gas is located in the Northeast-Southwest of the study area which in WCB-1, WCB-3, and WCB-4 well with the acoustic impedance values are in the range of 4.800-13.000 (m/s)*(g/cc), and the porosity values generated from the analysis using the multi-attribute seismic method are in the range of 5-16% in WCB-1 and WCB-4, 2-10% on WCB-3.

Keywords: *acoustic impedance, multi-attribute, model-based, stepwise regression*.

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INTRODUCTION

In this 21st Century, human dependency on oil and natural gas is inccreasing. The natural energy is needed to fulfill daily household life that is dominated using oil and natural gas, which are the main strategy of energy commodity in Indonesia. This increasement need to be balanced with the development of technologies used in natural resources exploration which can be carried out through one of the geohpysics methods, namely the reflection seismic method in the form of acoustic impedance inversion and multi-attribute.

Reservoir is the main target in the exploration of oil and natural gas industry. Reservoirs can be defined as storage spaces in the form of pores or cavities beneath the surface of the earth located between mineral grains or in rock fractures that contain low-value porosity and oil and natural gas as well. Therefore, analysis of reservoir characterization is need to be done by using the seismic inversion acoustic impedance and multi-attribute method to determine the actual subsurface conditions, especially in the reservoir zone based on geological modeling in the form of constituent lithology and fluid content [1].

This research was conducted in the Plover Formation, the Bonaparte Basin, which is the main object of exploration and has the prospect of hydrocarbons and reservoir lithology content in the form of coarse-fine sandstone with alternating shale and claystone.

Regional Geology

This research is located in the Bonaparte Basin which is in the Northern part of the passive boundary of the Australian plate and belongs to the Graben Calder. The Bonaparte Basin is composed of several sub-basins and exposure areas that exist since the Paleozoic and Mesozoic periods. The formation of this basin is generally controlled by two main phases, namely the extension phase which occurred during the Paleozoic period, then followed by the compression phase occurred in the Triassic era, and finally encountered a phase of extension again in the Mesozoic period and peaked when Gondwana Land in the Middle Jurassic era split.

The Bonaparte Basin approximately has an area of ± 270.000 m^2, lies along the offshore stretching from Western Australia to the Timor Sea. This area consists of fluvial, siliciclastic, and carbonate sediments with a thickness of up to 15 kilometers. This basin is located in an area belongs to three countries: Australia, East Timor, and Indonesia. The Northern part of the basin is directly adjacent to the Timor Gap, while the Southern part is directly adjacent to the city of Darwin in Northern Australia, and the western part is bordered by the open seas of Indonesia and Australia. The map of Bonaparte Basin is shown in Figure 1 [2][3].

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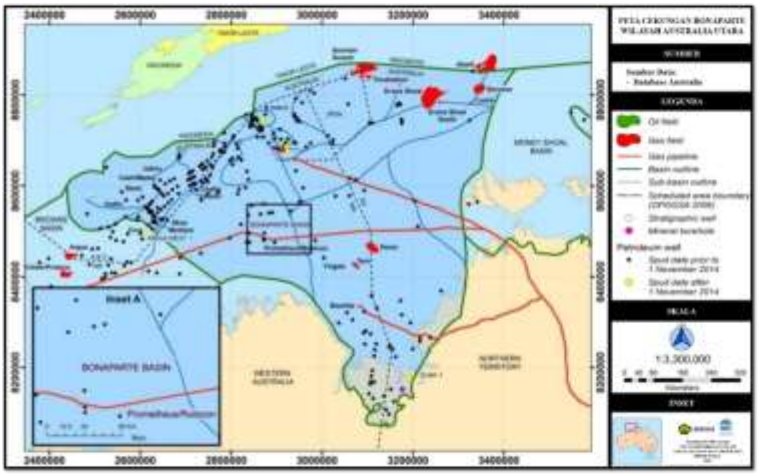

Figure 1. Map of Bonaparte Basin [4]

The Plover Formation consists of reservoir rocks that their structure are dominated by sandstone and alternatated with layers of clay and shale. This formation is divided into upper and lower Plover. The upper Plover is composed of the shallow seashore to the shore sequence sediments which are in the transgressive phase with its characteristics of either massive or layered sandstone of medium-coarse size, with more than 5 m thickness and inserted by clay rock. The lower Plover is composed of fluvio-deltaic sequence sediments which are in a regressive phase with its characteristics of a sandstone layer with medium-fine grains and thinner compared to the thickness of upper Plover and inserted by clay rock. The stratigraphy of target area at Bonaparte Basin is shown in Figure 2.

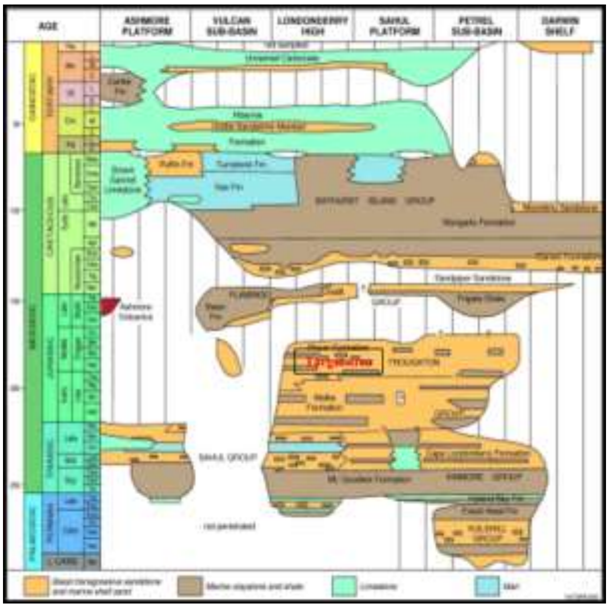

Figure 2. Bonaparte Basin Stratigraphy [5].

Seismic Reflection

Seismic reflection is one of the most important methods useful in supporting exploration in the oil and gas sector. Seismic reflection is used because this method provides more complete information and also able to explain and describe the subsurface structures more detail in three dimensions. To examine the subsurface of the earth with seismic reflection is used elastic sound waves. The elastic sound waves are emitted by a vibrating source in the form of dynamite explosions which are generally used during data acquisition on the land. Besides, there are also air guns, sparkers, and boomers which are generally used during data acquisition in the sea. The explosion produces waves that capable to penetrate rocks beneath the earth's surface. Later, it will be reflected in the form of a rock layer boundary to the earth's surface through its reflector plane. Then, the recording device in the form of a geophone on the land and a hydrophone in the sea will receive and record the waves which are then will be reflected back to the surface. During propagation, seismic waves are reflected from the boundary between two recorded rock mediums. The big changes of acoustic impedance (AI) that occurred between the two rock mediums are directly related to these seismic waves reflection. The Survey of Seismic Reflection at Sea can be seen in Figure 3 [6] [7] [8].

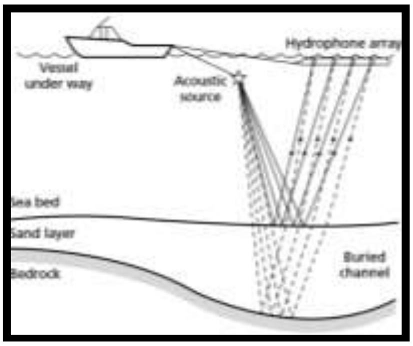

Figure 3. Seismic Reflection Survey at Sea [9].

Seismic Inversion

Seismic inversion is inverse modeling where its algorithmic modeling is a deconvolution between seismic recorded data and seismic waves, which then produces an acoustic impedance section related to the creation of a seismic section based on the shape of the earth. This method forms a geological model of the subsurface layer using two data in the form of seismic data as input and well data as control. This method involves mapping the physical structure and properties of the layers beneath the earth's surface by taking measurements on the earth's surface. The illustration of inversion seismic process is shown in Figure 4 [10].

The seismic inversion method is divided into two parts, namely the pre-stack inversion seismic and the post-stack inversion. The post-stack inversion is related to the amplitude inversion which consists of three types of modeling: recursive (bandlimited), sparse-spike, and model-based. This study used the post-stack inversion seismic method by using model-based modeling [11].

Post-stack model-based inversion has a principle on describing the geological model. The geological model needs to be compared with the real seismic data. Then, it will be used to update the previous model and adjust it to the seismic data. The advantage of using this method is it does not inverse the seismic directly, but inverses the geological model.

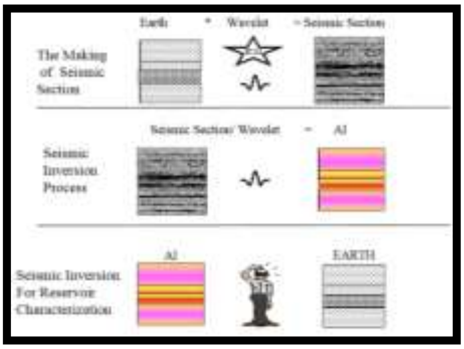

Figure 4. Illustration of Inversion Seismic Process [10].

Acoustic Impedance

Acoustic impedance is a nature of rocks which is influenced by porosity, depth, lithology type, fluid content, temperature, and pressure. Therefore, acoustic impedance is generally used as indicator of lithology, lithology mapping, porosity, seismic facies, flow mapping, hydrocarbons, as a means to quantify reservoir characters, formation of subsurface geological models. Acoustic impedance can transmit seismic waves on rocks [6] [12]. To define the acoustic impedance, use the equation below:

$$Z = AI = \rho \, . \, v, \tag{1}$$

where Z is the acoustic impedance (m/s)*(kg/m^3), ρ is the density (kg/m^3) and v is the velocity (m/s).

Multi-attribute Analysis

Multi-attribute analysis is a seismic method that using more than one attribute to estimate several properties of the physic of earth based on seismic data. This analysis is carried out to estimate the volume of log properties in all seismic volume locations by applying the relationships acquired from the results of log relationships and seismic data at the well locations. In reservoir characterization, statistics are used to predict the relationship between spatial variables at the desired value in a location where there is no sample data measurable.

Based on facts in nature, it is often that the measurement of variables which took place in an area that is close to each other has something in common. The alignment between two measurements will be inversely proportional to the distance, when the distance increased, the alignment of the measurements will be decreased. In fact, what is being analyzed is its seismic attribute data, not the seismic data, because it is more advantageous and able to increase the the prediction power, which is caused by several attributes that have non-linear characteristic [13].

In a multi-attribute analysis, there are three main sub-categories for identification, that is:

A. Extension of cokriging involved more than one secondary attribute to estimate the main parameter.
B. A covariance matrix is used to estimate parameters linearly based on the weighted input attributes.
C. Several seismic attributes are combined to estimate the required parameters by using Artificial Neutral Networks (ANNs) or non-linear techniques.

Linear regression method is used to determine the relationship between the target log and the attribute than show as crossplot. This method can be explained by equation:

$$y = a + bx. \quad (2)$$

Where y is the predicted value, a is the intercept that estimated by regression, b is coefficient that estimated by regression, and x is the predictor that present in data.

Stepwise regression technique is used to know how to determine the best attribute combinations that are most effective in predicting a log target with several steps. First, determine the single best attribute by trial and error and has the lowest prediction error and call this one attribute. Second, determine the best pair of attributes with the lowest prediction error and call this second attribute. Third, determine the best triplet of attributes with the lowest prediction error and call this third attribute. Carry on this process as long as desired.

METHODS

This research was conducted in the KP3T Field of the Exploration Building 3 Research and Development Center for Oil and Gas Technology (PPPTMGB) "LEMIGAS" located on Ciledug Raya Kav. 109 Cipulir St, Kebayoran Lama, South Jakarta City, Jakarta 12230. The research took place from February to August 2020. The research area was in the Bonaparte basin and using methods such as seismic inversion acoustic impedance and multi-attribute. The research data that were used are 3D Post-Stack Time Migration (PSTM) seismic data; 4 well data consisting of Gamma Ray log, Resistivity log, NPHI log, RHOB log, P-Wave log, PHIT log, and Sw log; marker data, and checkshot data.

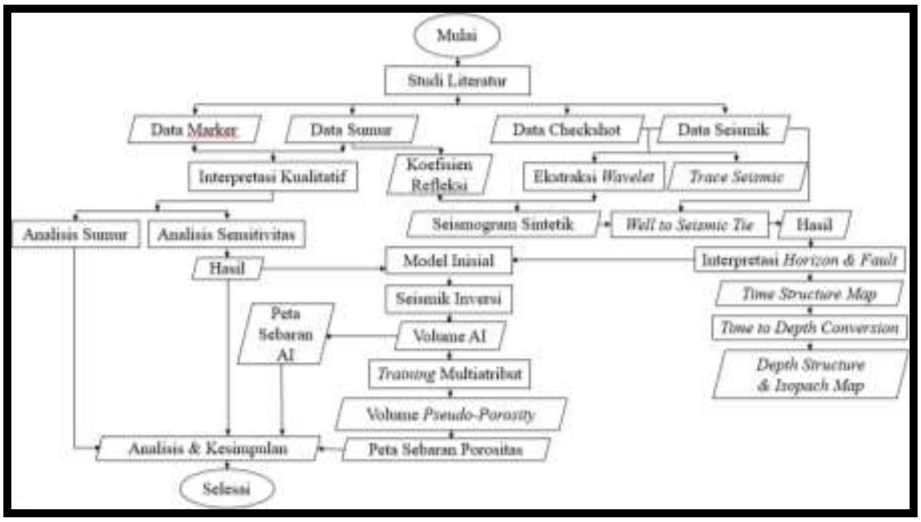

Figure 5. Research Flowchart

Data processing was carried out by using the CE8R4 version of Hampson Russell Software (HRS) for seismic and well data processing to AI inversion and multi-attribute to determine the characteristics of the reservoir zone in each well. Then, Petrel software is used for horizon interpretation by drawing continuity lines on the reflector plane and faults by drawing continuity lines on the fault plane, time to depth convertion, and create structure and surface map in the time and depth domain. The flow chart of well analysis and seismic inversion untill multi-attribute is shown in Figure 5.

Interpretation to determine the characteristics of the reservoir in this study was carried out by correlating the results of data processing, regional geological information of the research area, and information of the value in each log and the porosity table.

RESULT AND DISCUSSION

Target Zone Analysis Based on Well Log Correlation

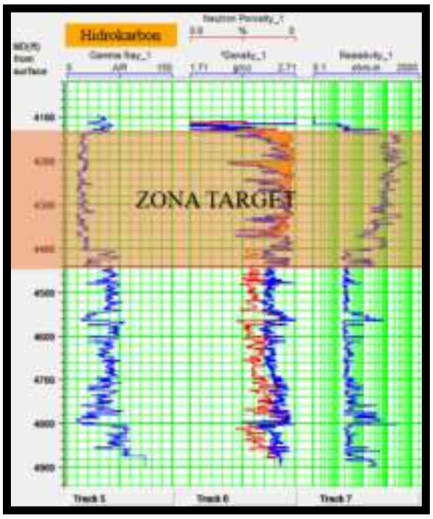

Figure 6. Quicklook Target Zone Analysis of WCB-3 Well

The result of the quicklook analysis of the research target reservoir zone at WCB-3 well is shown in Figure 6. The display of the gamma ray log curve shows the presence of a permeable layer reservoir zone because it has low gamma ray values ranging from 10-60 API with lithology in the form of sandstone. Moreover, there is a cross over between the NPHI log and the RHOB log which indicates the presence of hydrocarbons containing fluid in the reservoir zone with a depth of 4.140 to 4.440 ft. The response of LLD resistivity log is used to determine the fluid content, where the LLD resistivity log with high value and has more than 80 Ohm. This indicates that there is a fluid content in the form of gas in the target zone of WCB-3 well in the research area (Table 1) [14].

Table 1. Results of Target Zone Analysis Based on Well Log Correlation

Well	Gamma Ray (API)	Cross over NPHI & Density	Resistivity LLD (Ohm)	Depth (ft)
WCB-1	Low	Exist	>80 Ohm	3.910 – 4.220
WCB-2	Low	Doesn't Exist	<80 Ohm	4.300 – 4.575
WCB-3	Low	Exist	>80 Ohm	4.140 – 4.440
WCB-4	Low	Exist	>80 Ohm	4.170 – 4.490

Sensitivity Analysis

According to the results of the crossplot on the target zone which refers to regional geology is shown in Figure 7, the separation of lithology is divided into two zones: a zone that is composed of shale lithology with green colored and a zone that is composed of

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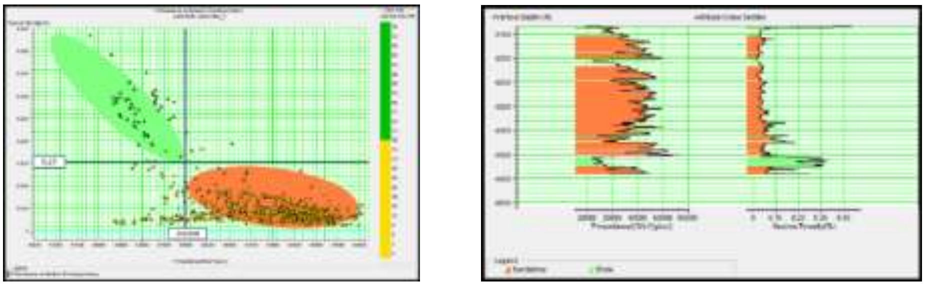
sandstone lithology with peach colored. This analysis is considered sensitive because it can separate the two lithologies well and determine the relationship between acoustic impedance and porosity which is inversely proportional.



(a) (b)

Figure 7. (a) Crossplot Results on WCB-3, (b) Cross-Section View on WCB-3

Besides, cut-off or or acoustic impedance limitiation for both zones is 30.000 (ft/s)*(g/cc) and a porosity cut-off (NPHI) of 0,15. It can be inferred that the reservoir zone of the WCB-1, WCB-3, and WCB-4 wells are composed of sandstone lithology, while the WCB-2 reservoir zone is composed of sandstone lithology but dominated by shale inserts.

Well to Seismic Tie **Analysis**

According to the result analysis using wavelet ricker, the author argue that synthetic seismograms have similarities with seismic traces and have maximum correlation value and minimum time shift. This indicates that the result obtained from the well seismic tie process is quite good. Therefore, it helps in interpreting the horizon which is will be referred while picking. It can be seen that the TOP-X horizon in seismic data is at the peak, while the BASE-Y horizon is on the through (Table 2).

Table 2. Correlation of Well To Seismic Tie in Each Well

Number	Well	Correlation	Time Shift (ms)
1	WCB-1	0,939	0
2	WCB-2	0,810	0
3	WCB-3	0,802	0
4	WCB-4	0,914	0

Horizon and Fault Interpretation

Interpretation of the horizon is carried out by pulling the continuity of the seismic reflector based on the presence of the TOP-X and BASE-Y target zone markers that have been carried out in the well seismic tie as a reference. Meanwhile, fault interpretation is carried out by drawing a line on the fault plane based on regional geological information in the NE-WS (Northeast-Southwest) and shown in Figure 8.

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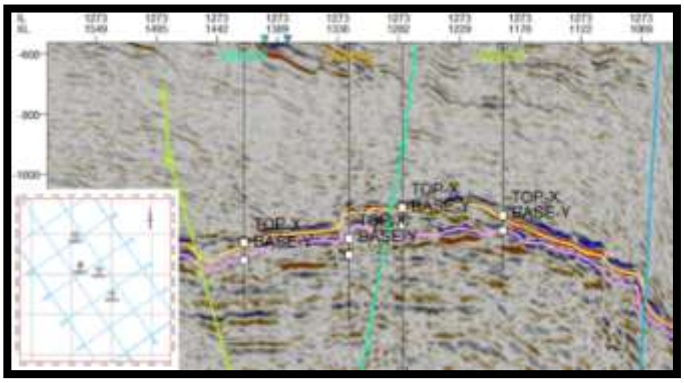
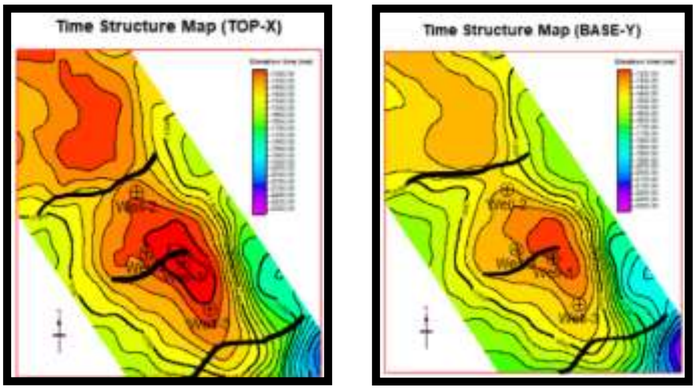


Figure 8. Display of Horizon and Fault Interpretation

Time and Depth Structure Map

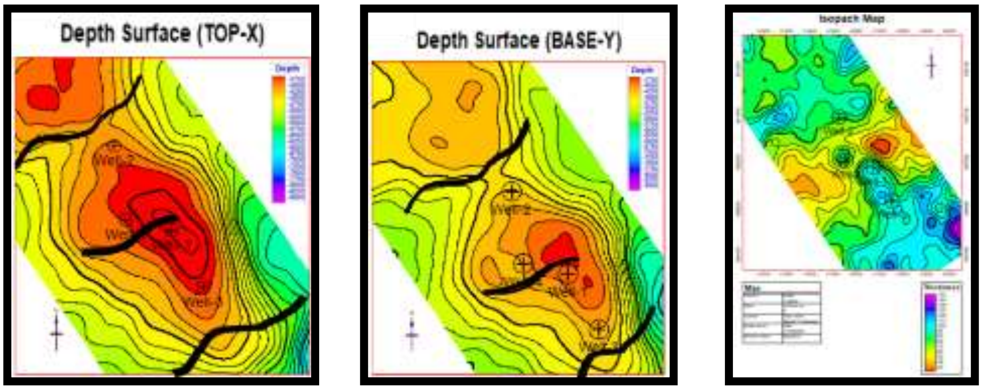
The time structure map at the top and basement of the research target reservoir zone is used to determine how the structure condition is in the time domain. According to the time structure map in TOP-X and BASE-Y is shown in Figure 9, it can be seen that the reservoir zone is in one closure which is higher area compared to the surrounding area, and has domain time in the range of 1.200-1.400 ms.



(a) (b)

Figure 9. Time Structure Map (a) Horizon TOP-X, (b) Horizon BASE-Y

Meanwhile, the depth structure map is used to determine the condition of the structure in the depth domain and it can be seen that the reservoir zone on both horizons is at one closure which is a higher area compared to the surrounding area and the depth structure map is shown in Figure 10.



(a) (b) (c)

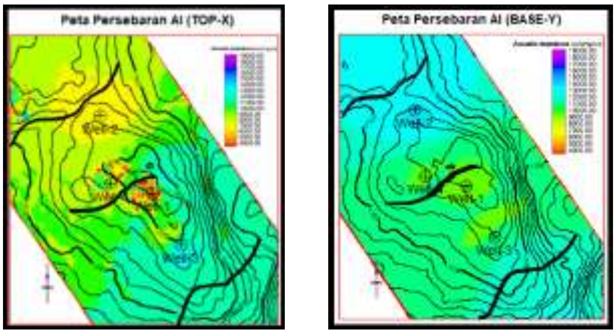
Figure 10. (a) Depth Structure Map of Horizon TOP-X, (b) Depth Structure Map of Horizon BASE-Y, (c) Thickness Map

Table 3. Depth and thickness domains for each well

Well	Depth Domain		Thickness
	TOP-X	BASE-Y	
WCB-1	3.500 ft	4.000 ft	88-104 m
WCB-2	3.750-4.000 ft	4.500 ft	72-88 m
WCB-3	3.500 ft		88-104 m
WCB-4		4.250 ft	72-104 m

Analysis of Acoustic Impedance Seismic Inversion

According to the results of the acoustic impedance inversion section in the form of a model-based, it can be inferred that the reservoir containing sandstone has an AI value in the range of 4.800 (m/s)*(g/cc) to 13.000 (m/s)*(g/cc) which marked in light green to dark blue. This is in accordance with the results of well log data calculations. After that, the slicing was carried out on the cross-section of the inversion to determine the lateral distribution pattern of AI values.



(a) (b)

Figure 11. Map of AI Distribution Display (a) Horizon TOP-X, (b) Horizon BASE-Y

According to the AI distribution map in Horizon TOP-X, the WCB-1 Reservoir Zone which is inline 1281, the AI values range from 4.800 (m/s)*(g/cc) to 7.000 (m/s)*(g/cc) marked in orange to yellow. The WCB-2 Reservoir Zone which is in inline 1281, has an AI value of 7.000 (m/s)*(g/cc) which is marked in yellow. Meanwhile, the WCB-3 Reservoir Zone which is in inline 1273, the AI value ranges from 11.000 (m/s)*(g/cc) to 13.000

(m/s)*(g/cc) which is marked in greenish blue until light blue. For the WCB-4 Reservoir Zone which is in inline 1237, the AI values range from 4.800 (m/s)*(g/cc) to 11.500 (m/s)*(g/cc) marked in orange to greenish blue.

According to the AI distribution map on Horizon BASE-Y, Reservoir Zone on WCB-1 and WCB-4, the AI value is 10.000 (m/s)*(g/cc) marked in green. While the WCB-2 Reservoir Zone, the AI value is 13.000 (m/s)*(g/cc) marked in blue. While the WCB-3 Reservoir Zone, the AI value is 11.000 (m/s)*(g/cc) marked in turquoise blue. The map of AI distribution is shown in Figure 11.

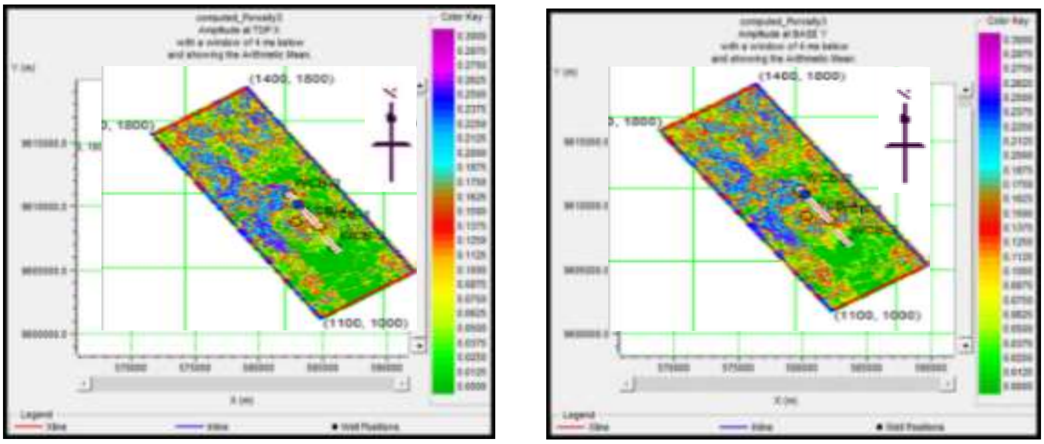
According to the AI distribution map on both horizons that are correlated with regional geological information, density log data, and the results of the sensitivity analysis, it can be inferred from reservoir zone in WCB-1 and WCB-4 that their constituent lithology are sandstone that is porous because it has a relatively low density when compared with the reservoir zone in other wells. Whereas in the WCB-2 reservoir zone, its constituent lithology is sandstone inserted by shale rock because it has a relatively large density value when compared to the WCB-1 and WCB-4 reservoir zones. Then, for the WCB-3 reservoir zone, its constituent lithology is compact sandstone because it has a large density value when compared to the reservoir zones in other wells.

Multi-attribute Analysis

According to the pseudo-porosity cross-section by applying the linear regression method and stepwise regression technique that using 10 attributes with 9 operators length, the author assume that there is an alignment between the color and the log porosity values contained in the well and the porosity log predicted in this analysis using 8 out of 10 existing attributes. This is caused by the increasement in validation error value and the validator curve in the ninth attribute which indicates overtraining. After that, the slice is made with a 4 ms window under the horizon to form a map porosity distribution in the research area.

According to the porosity distribution map in the both horizon is shown in Figure 12, the reservoir zone in WCB-1 and WCB-4 is a hydrocarbon prospect zone that has a porosity value in the range of 5% to 16%. Meanwhile, the WCB-3 reservoir zone which is a hydrocarbon prospect zone has a porosity value in the range of 2% to 10%. Then, WCB-2 which does not have hydrocarbon prospect has a porosity value that is in the range of 3% to 12%.

According to the porosity distribution map in the both horizons which is correlated with regional geological information, density log data, and the result of the sensitivity analysis, it can be seen that the WCB-1 and WCB-4 lithological reservoir zones are composed of sandstone that is porous because it has a relatively low density when compared with the reservoir zone in other wells. Whereas in the WCB-2 reservoir zone, its constituent lithology is sandstone inserted by shale rock because it has a relatively large density value when compared to the WCB-1 and WCB-4 reservoir zones. Then, for the WCB-3 reservoir zone, its constituent lithology is compact sandstone because it has a large density value when compared to the reservoir zones in other wells. Also, it can be seen that the distribution of the reservoir in the study area leads to the Northeast-Southwest and is in one closure in an elevated area.



(a) (b)

Figure 12. Map of Porosity Distribution (a) Horizon TOP-X, (b) Horizon BASE-Y

By using the methods, both the acoustic impedance inversion seismic method and the multi-attribute seismic method, it can be inferred that the similiar distribution pattern or trend is obtained. Where the reservoir zone that has hydrocarbon prospects is in the Northeast-Southwest part with a relatively low acoustic impedance value and high porosity value obtained from multi-attribute analysis in shaft sandstone. Meanwhile, compact sandstone has a high acoustic impedance value and a relatively low porosity value. According to the porosity classification table, the resulting porosity values in the multi-attribute analysis in this study were classified into bad porosity in the reservoir that has <10% porosity value, but in some areas that has 10% to 16% and classified into good porosity with low acoustic impedance value has hydrocarbon prospect.

CONCLUSION

According to the results of research on the application of the acoustic impedance seismic inversion and multi-attribute method for reservoir characterization in the Bonaparte Basin, can be inferred as follows:

1. WCB-1, WCB-3 and WCB-4 wells in the research area are the locations that potentially become hydrocarbon reservoir zones.
2. The distribution of sandstone reservoirs that potentially contain gas hydrocarbons in this study is located in the Northeast-Southwest and is in high areas, and the characteristics of the reservoir based on the acoustic impedance value are in the range of 4.800 – 13.000 (m/s)*(g/cc) obtained by the seismic inversion acoustic impedance method.
3. The distribution of sandstone reservoirs that potentially contain gas hydrocarbons in this study is located in the Northeast-Southwest and is in high areaa, and the characteristics of the reservoirs WCB-1 and WCB-4 based on their porosity values are in the range of 5% to 16% while The WCB-3 reservoir is in the range of 2% to 10% obtained by the multi-attribute seismic method.

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