Basement Fractures Forward Modelling Using Framework Model Derived From 3D Seismic Interpretation

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Abstract. Mapping fractures in basement plays important part in prospect maturation of fractured basement reservoir play. Several seismic attributes may portray any discontinuity features interpreted as fractures. However, the seismic-scale fractures would not be enough to explain the conductivity of the fractures, which is important to define it as a potential reservoir. Fracture modelling by applying certain geomechanics parameters as well as present day stress condition would be one of method to address the matter. This paper aims to predict the fractures distribution and its conductivity through Boundary Element Method (BEM) forward modelling in study case of South Sumatra Basin. The fracture modelling relies the most on the seismic interpretation of the high resolution and beam migration 3D seismic data. Horizon and faults interpretation were used as the mechanical boundary in this modelling. Total of 47 major and 122 minor faults were interpreted and used for the modelling. The simulated fractures resulted from the modelling then being further analyzed for its hydraulic conductivity through slip tendency approach. The fracture modelling result shows most of the fractures have the orientation of NE-SW. The modelling also shows the study area has pretty intense of deformation process resulted from the strain magnitude model. The slip tendency result shows most of the fractures are in the critically stressed condition or hydraulic conductive towards the present-day maximum stress condition. Last, certain areas can be defined as reservoir targets based on high value of strain magnitude and slip tendency.

Keywords: seismic interpretation, fracture modelling, boundary element method

1. Introduction

Fractured basement reservoir potentials have been proven in several areas especially in the South Sumatera Basin. Another area in the South Sumatera Basin that worth to be explored is located in the Merang High of the Jambi sub-basin, which became the area of this study. Two major tectonic events in the South Sumatera Basin are well imprinted as today's structural features. Those are the extensional phase and inversion phase. The extensional phase occurred in the Late Paleocene to Early Miocene, formed several horsts and grabens in north-south direction. Those horsts and grabens later experienced the rotation of 15 degrees clockwise in Miocene turning the trend into northeast-southwest (Hall, 1995), which can be seen as today's main basins configuration in the South Sumatera Basin. As for the inversion phase, it was occurred in the Plio-Plistocene forming several younger structures in northwest-southeast trend. Typical anticlines and strike slips faults were formed in this phase (Ginger&Fielding, 2005).

The study area is situated in high structured basement and affected by multi-phase tectonics. This Pre-Tertiary basement is composed by metamorphic rock of quartzite lithology. Dealing with fractured basement play in exploration is unlike the conventional one. Understanding the fractures distribution and its characters towards present-day in situ stress condition, are important to define the potency of fractured basement reservoir. When seismic attributes can only show fractures distribution by identifying them as discontinuity features in seismic image, further analysis like fracture modelling would be necessary to perform in order to demonstrate the fracture mode, orientation and density. Also, not all open conductive fractures are always hydraulically conductive. Fractures should be in critically stressed state in regards to present-day in situ stress, so that it could become a good permeable reservoir. Slip tendency approach is one of methods to analyze the tendency of fractures to be in the critically stressed condition. The aim of this study is to map the fractures distribution and analyze its characters towards the present-day in situ stress condition through forward modelling using Boundary Element Method (BEM). As the study area has limited data of offset well, this study relied the most on the high resolution and beam migration 3D seismic data. The main input for the modelling is the framework model derived from horizon and faults interpretation so subsurface mapping need to be done thoroughly that a reliable framework model can be used.

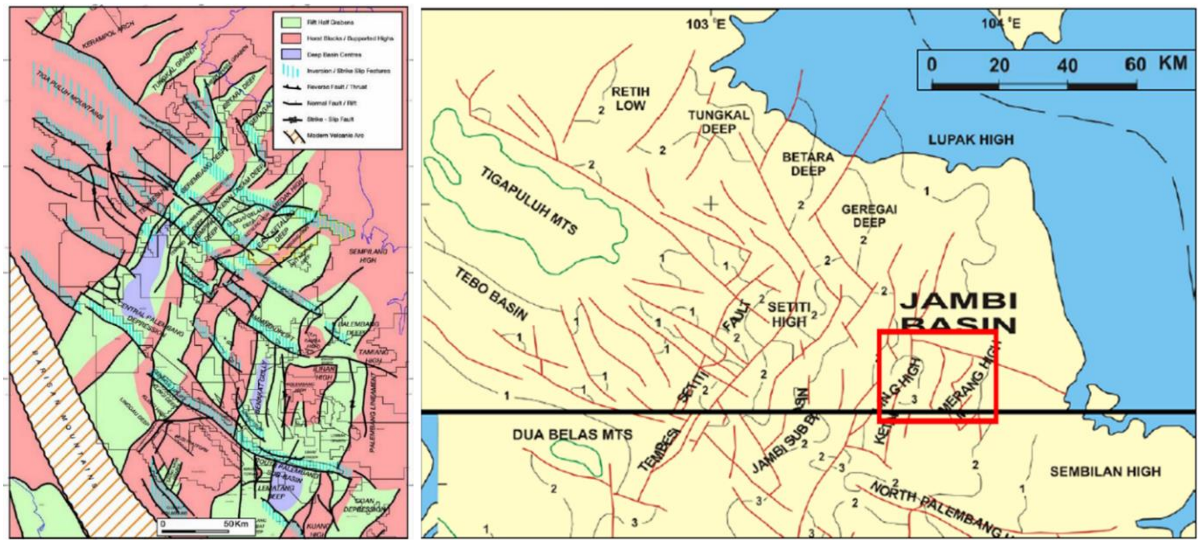


Figure 1. Tectonic element in South Sumatera Basin and study area (Mod. Ginger & Fielding,2005)

2. Data and Methodology

Main data used for this study are the 3D seismic data in PSDM and reference wells. Only 1 offset well available inside the study boundary. Nevertheless, any other well references in the working field area also be used to support rock physics or mechanic parameters. The methodology used in the study is described in the workflow below (Figure 2).

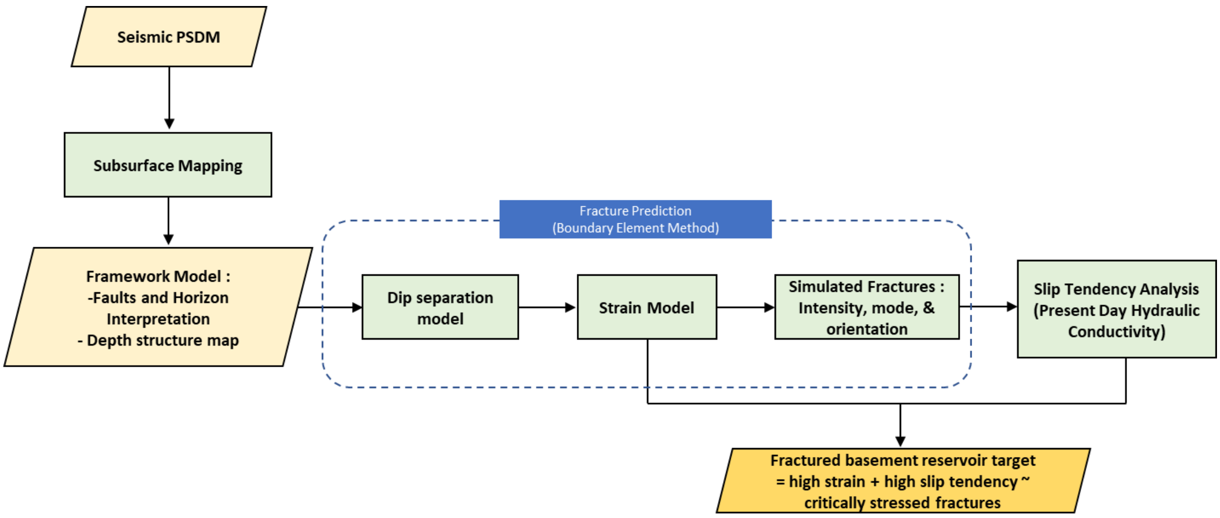


Figure 2. The study workflow.

2.1. Subsurface Mapping

The interpretation was conducted mostly in PSDM data as it has better image resolution compared to the PSTM. Pseudo-relief attribute was chosen to help distinguishing faults features, not only for the major but also minor faults. Horizon and faults were thoroughly picked to create the framework model in the study area. The framework model resulted in depth structure would help understand the geological framework of the study area. While the horizon and faults plane would be the main inputs for fracture modelling.

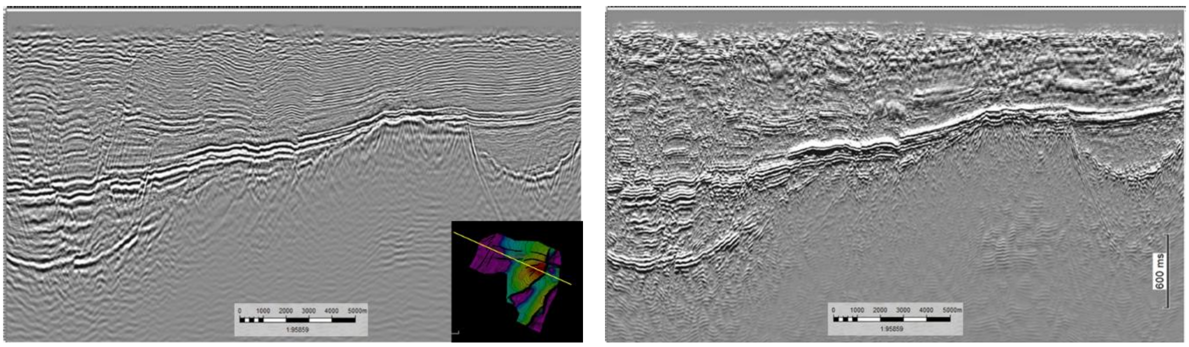
2.2. Fracture Prediction

The fractures were predicted through forward modelling using Boundary Element Method (BEM). This method uses the faults plane from seismic interpretation as its mechanical boundaries. The goal from this method is to demonstrate the intensity of deformation through strain magnitude model and also the fracture mode, density, and orientation. In this part, several steps are conducted. Firstly, Displacement Discontinuity Method (DDM) is conducted to create dip separation model that would result the best model matched with the framework model. Various regional boundary conditions are tested until the most similar model to the observed is reached. As for this study, dip separation from dip attribute is chosen to become the observed framework model. However, this solution barely will be resulted perfectly due to many constraints. Similarity of 10-15% to the observed is already considered good match. The DDM solution would generate strain values on each observation points from fault displacements accordingly to the given regional boundary conditions. This strain values then will be forward modelled into the strain magnitude model. Strain magnitude approach was used in this study, because it can represent the total of three-dimensional strain tensor on each point of observations. Accumulated regional strain impact to the forming of fault slip. From strain magnitude, stress tensor can be calculated using Hooke principal. Then, the fractures can be calculated as well by calculating the total stress compared to the stress condition of the Mohr-Coloumb failure envelope. Fractures can only be formed when it exceeds the failure envelope (Jaeger et al., 2007). Furthermore, the result of simulated fractures is associated with present-day maximum stress to see its tendency to be in critically stressed condition. Slip tendency approach is used to assess the tendency of a surface to undergo slip in a given stress field depends on its frictional characteristics and the ratio of shear to normal stress acting on the surface (Morris et al, 1996).

3. Results and Discussion

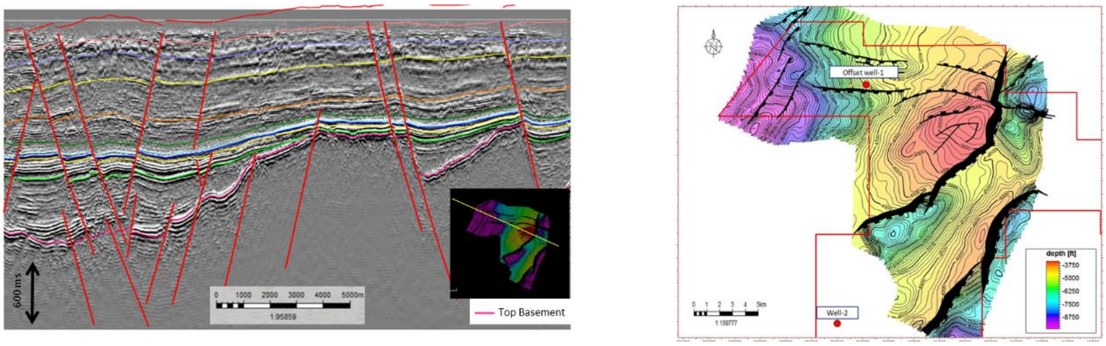
3.1 Subsurface Mapping

Discrepancy between the basement and sediment strata in the seismic section is pretty clear, especially with a help from pseudo-relief attribute (Figure 3). In general, most of the faults interpreted have vertical offset which defined as normal faults. These set of normal faults have relative direction of N-S to NE-SW. Other faults interpreted in the study area are the ones with E-W direction. These E-W trending faults have no such significant offset yet quiet long lateral continuity. In certain area (Figure 4), it can be seen the E-W trending faults intersect the NE-SW trending fault. It can be presumed that the NE-SW trending faults are the faults formed in the extensional phase while the E-W trending faults formed in the inversion phase referring to the tectonic history of South Sumatera Basin. Based on the displacement analysis, it can be interpreted the E-W trending fault is left lateral strike slip fault due to its sinistral movement.



(a) (b)

Figure 3. Original PSDM data (a), Pseudo relief attribute (b)



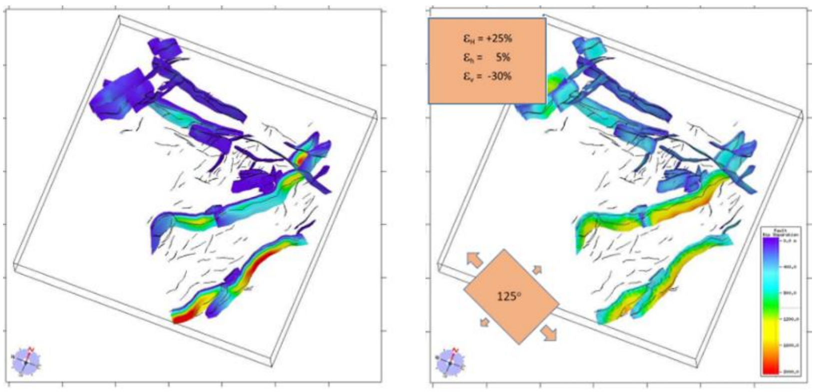
(a) (b)

Figure 4. Horizon and fault picking on a section (a). Basement depth structure map result (b).

3.2 Fracture Prediction

Total of 47 major and 122 minor interpreted faults were used as input for boundary model. The DDM simulation were conducted for over 42 times until the best result was reached. The scenario of boundary condition applied for this study was the trans tensional regime with 25% extension and 125° stress orientation (Figure 5). This particular condition is result from trial-and-error process so that it does not have to represent the actual geology condition at certain time. The result of modelling the strain value based on the DDM simulation can be seen in Figure 6. The red color defined the highest value of strain in which the most intensity of deformation had occurred there. However, the range value from this model was already quite big for strain. So, the area with blue ones do not mean the intensity of deformation is small.

Based on diagram rose of the simulated fractures (Figure 7), these fractures mostly have the orientation of 20-30° NE. Meanwhile, the present day in-situ stress direction is relatively NE as well. This makes the present day SHmax is generally obliqued to the most of fractures. The more obliqued they get; the more fractures would be in critically-stressed condition. Those parameters were used in slip tendency calculation. The result of slip tendency map can be seen in Figure 8. The red area from the map shows the highest value of slip tendency, which have the most of fractures in the critically-stressed condition. Those particular areas are considered to have good conductivity, not to mention the strain magnitude map (Figure 6) also necessary to put into consideration. The area with high strain and high slip tendency tend to become the most prospective reservoirs (Figure 9).



(a) (b)

Figure 5. Observed dip separation (a), the model of dip separation by applying certain regional boundary conditions.

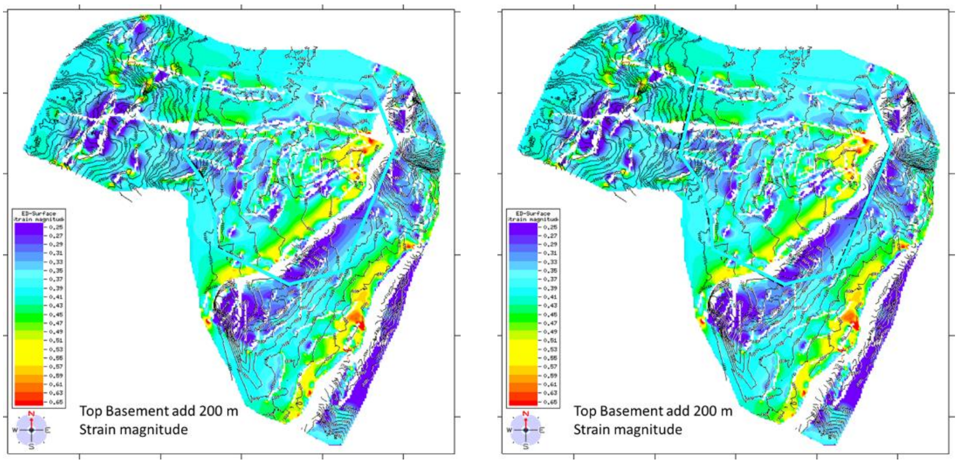
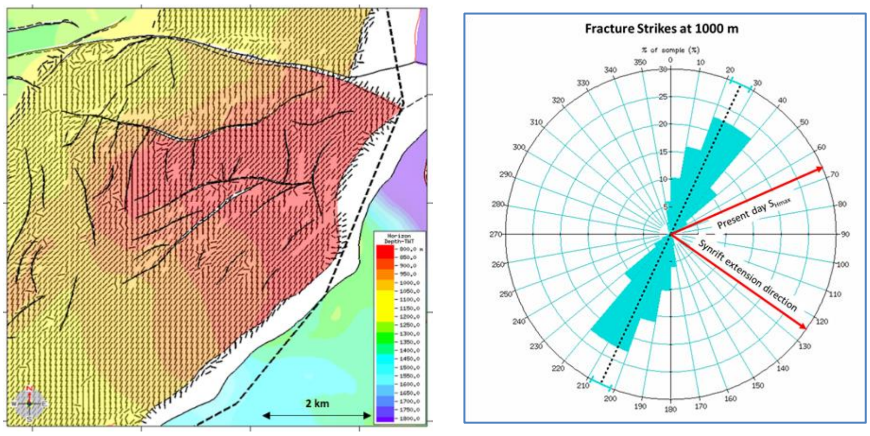
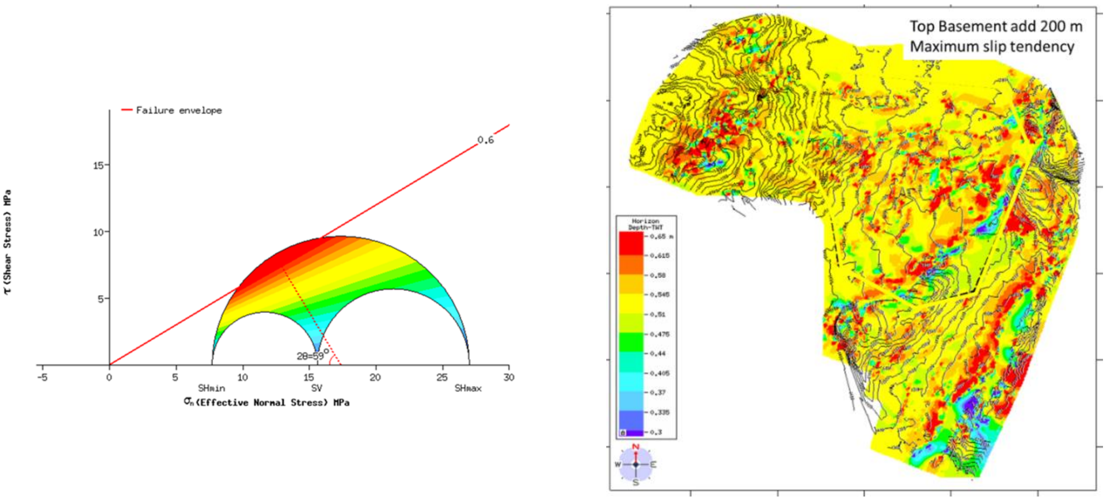


Figure 6 Strain magnitude model demonstrates the intensity of deformation



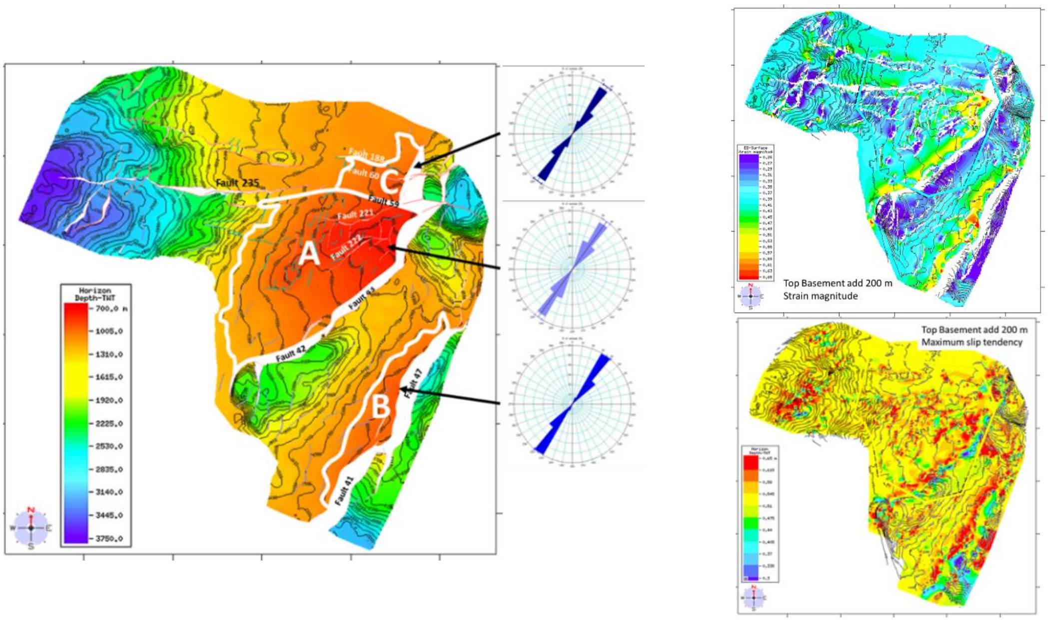
(a) (b)

Figure 7. Simulated fractures result (a), orientation of simulated fractures (b)



(a) (b)

Figure 8. Sensitivity analysis fractures on Mohr Diagram (a), result of slip tendency (b)



(a) (b)

Figure 9. Assessing potential fractured basement reservoir targets (a) based on strain magnitude and slip tendancy value (b).

4. Conclusions

Based on our study, we can summarize it into several points as follow;

1. The structural framework of the study area have two main typical faults. The NE-SW normal faults and E-W left lateral strike slip.
2. Total of 47 major and 122 minor interpreted faults were used as input for boundary model. Regional boundary of trans tensional regime with 25% of extension and 125^o orientation was applied to generate best matched model to the observed interpretation.
3. The simulated fractures from modelling have main orientation of 20-30^o NE.
4. The present day in situ stress condition have orientation relatively obliqued to the most of simulated fractures
5. The area with high slip tendency and strain value is considered as the most prospective fractured basement reservoir.

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Reservoir Characterization Using Acoustic Impedance (AI) Seismic Inversion and Seismic Multi-Attribute, Case Study: "BM" Field, Bintuni Basin, West Papua

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Abstract. "BM" Field is one of the oil and gas field at Bintuni Basin, West Papua, Indonesia. This field produced crude oil, that is originated from Late Miocene Kais Formation limestone. Other than crude oil, this field also has natural gas potential from Roabiba Sandstone reservoir in Jurassic Lower Kemblangan Formation. Reservoir characterization can be done using two main types of data which are seismic data, well log data, and supported by geological data. There are two methods that can be used together in integrating seismic and well log data which are acoustic impedance seismic inversion and seismic multi-attribute. The processes started with sensitivity and petrophysical analysis of well logs data, followed by well seismic tie using both of seismic and well logs, and finally structural interpretations of the seismic data. Seismic inversion process will distribute AI value, that has been analyzed as correlated to the porosity data, to all the seismic lines. Seismic multi-attribute will also use the inverted AI results as the external attributes and other trained seismic attributes to predict porosity parameter of the seismic lines that later will be distributed to the research zone. Analysis results showed that there is a positive flower structure that act as the hydrocarbon's trap and migration pathways. Targeted Kais Formation and Roabiba Sandstone zone AI value is in the range of 20.000-50.000 g.ft/cm.s with its dominant distribution direction is Northwest to Southeast. There is also an AI value anomaly on top of the Kais Formation that is indicated caused by shale dominance on top of Kais Formation. It is confirmed further by its absence on Kais Formation multi-attribute porosity map. According to the porosity map, Kais Formation's porosity value is in the range of 5-25%.
Keywords: seismic, inversion, multi-attribute, reservoir, porosity

1. Introduction

Energy is vital to human lives in this modern day. It is also related to the unstoppable growth of the human population each year. Of all of the energy needs around the world, 80% of the supply comes from oil and gas energy which are still irreplaceable. BM Field is one of the fields that is located in the Bintuni Basin. The first discovery in Bintuni Basin was the oil discovery in Kais Formation limestone and several years later the biggest gas discovery as of 23.6 MMSCFGPD was founded in Bintuni Basin inside Middle Jurassic sandstone, it also marked the first Mesozoic hydrocarbon discovery in Indonesia [1]. It is also identified that the BM Field area has a great petroleum system including its components and processes, that will support the occurrence and accumulation of hydrocarbon [2]. Reservoir characterization is one of the processes to describe quantitatively and qualitatively reservoir rock's characters using several data such as geology data, seismic data, and well log data. Two of the methods that can be used are Acoustic Impedance (AI) seismic inversion to determine reservoir rock's porosity using AI parameters and seismic multi-attribute to combine AI inversion parameter with the other seismic attributes to predict reservoir rock's porosity more accurately [3]. The results from both of the methods then will be analyzed and compared to determine prospect zones and hydrocarbon zone spread patterns. The petrophysical analysis results are validated using the core data of each well.

2. Data and Methodology

The three data that were used are geological, wireline logs, and 2D PSTM seismic data. Wireline log data was used to determine rock's porosity and shale volume by doing a petrophysical analysis. Starting from the shale volume determination using the gamma-ray log, as its value represents the rock's radioactivity that was affected by its shale components, followed by porosity determination for each

well K-3, K-5, and KD-1 using the density-neutron method. The petrophysical analysis results were then validated using the core data of each well. The wireline log data was further used in the well seismic tie process to integrate its domain with the seismic data time domain. The KD-1 well's check shot data was used to tie all of the wells. Using 26 different distinct parameters wavelets with two extraction methods which are, statistical and use-well methods to find and determine the best parameters combination for the wavelet with the best correlation value across all of the wells.
The structural interpretation was carried out using the seismic data to determine faults and formation continuity (horizon) subsurface. It also must be correlated to the regional geology condition of the area. It is important to make sure that the well seismic tie process is carried out correctly before doing the structural interpretation. The output of the process was time structure maps on each of the targeted formations. The time domain structure maps then were converted into distance domain to make an easier analysis and inversion process using the velocity surface method and followed by further well-adjustment. The structural interpretation results are then used in the acoustic impedance (AI) seismic inversion. The inversion was used to predict reservoir rock's porosity using its AI parameters. Rock's AI parameters can be used to predict rock's porosity values based on their relationship which must be proven first using sensitivity analysis on the wireline log data [4]. The inversion process started by making an initial model to spread the AI parameters, which can be calculated from sonic (DT) and density (RHOB), on each well. Then, it was followed by the pre-inversion analysis to determine the correlation between the AI parameters from the wireline log data and the inversion results. In this research, the inversion was carried out by using a model-based inversion method, and the evaluation was done based on its error and correlation values [5].
The last process was the seismic multi-attribute analysis. This process predicted rock's porosity more accurately using a combination of multiple seismic attributes simultaneously [6]. The process included trial and error to determine the most optimal combinations of the seismic attributes. As a result, seven operators' lengths and eight maximum attributes were used in this process. It was done on each of the lines. It is vital to make sure that it is also geologically correct by correlating it with the geological data. After the correlation between the predicted logs and the original log values was decent and acceptable, it was decided to apply the multi-attribute to the seismic data. Both methods' results, then were analyzed and compared to determine the prospect zones as well as the reservoir rock's porosity distribution.

3. Results and Discussion

Clay Volume (VCl) and Porosity Log Calculation

The clay volume log was calculated using the gamma-ray log, so it was done along the gamma-ray log interval in each well. The result showed low clay volume tendencies inside the targeted zone as the porous zone would correlate with low clay content. On the other hand, the porosity log calculation was done by using the density-neutron method which is based on the correlation of density log and neutron porosity log to determine the porosity values.
As can be seen in Table 1. is the results of clay volume and porosity calculation in Kais Formation and Roabiba Sandstone from each well. Starting with the Kais Formation, the average clay volume for each well is 0.25 on KD-1, 0.23 on K-3, 0.28 on K-4, and 0.15 on K-5. The porosity value average is 18.16% on KD-1, 11.45% on K-3, 4.4% on K-4, and 5.16% on K-5. The Roabiba Sandstone calculation could only be conducted on the KD-1 well since it was the only well that reached the Roabiba Sandstone interval. The clay volume average is 0.43 and the porosity value average is 8.4% on the KD-1 Roabiba Sandstone interval. The results showed that Kais Formation and Roabiba Sandstone intervals were great potential reservoir target zones with their low VCl tendencies and good porosity value.

Table 1. Clay volume and porosity log calculation results

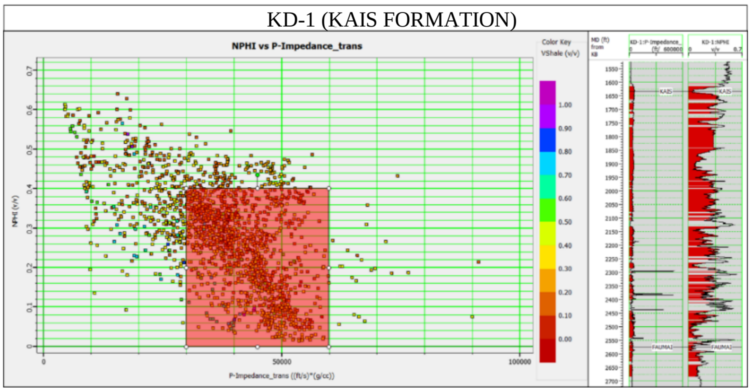
Well	Interval	VCl (v/v)	Phie (v/v)
KD-1	Kais	0.25	18.16%
	Roabiba Sandstone	0.43	8.4%

K-3	Kais	0.23	11.45%
K-4	Kais	0.28	4.4%
K-5	Kais	0.15	5.16%

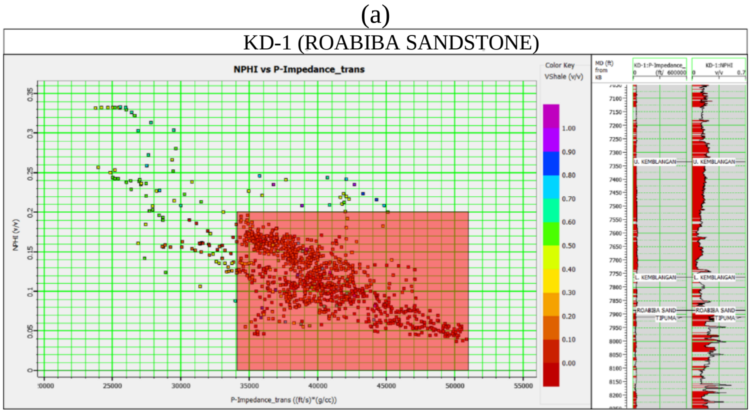
Sensitivity Analysis

The sensitivity analysis is vital in lithology and reservoir zone delineation. The correlation between acoustic impedance and porosity correlation was also determined by this process. According to the analysis results, as shown in Figure 1 and Figure 2, it could be identified the reservoir zone, which is indicated by low gamma-ray log value, had high p-impedance and low neutron porosity value characteristics. A low gamma-ray log value is associated with limestone and sandstone as potential reservoir rocks.

According to the results, the data could be considered sensitive to separate porous and non-porous zone and also can be seen by its good lithology separation on the cross plot. Based on the data cross plot results, the lower threshold of NPHI value is 0.2 and the maximum threshold of p-impedance value is 34000 (ft/s)*(g/cc) for the Roabiba Sandstone interval, as for the Kais Formation interval the minimum threshold of NPHI is 0.4 and the maximum threshold of p-impedance is 300000 (ft/s)*(g/cc). This positive result showed that the data was possible to be used in the AI seismic inversion.



(a)



(b)

Figure 2. Data *crossplot* and *cross-section* (a) Kais Formation, (b) Roabiba Sandstone

Well Seismic Tie

Well seismic tie process was done by correlating seismic data's seismogram with the wireline log's synthetic seismogram data, evaluated by each wavelet with different parameters to determine the most suitable wavelet parameters across all the wells. There were a total of 26 wavelet parameters evaluated and the average correlation value from each wavelet evaluation was used to determine the best wavelet for all of the wells. The best wavelet that was tested had 0.734 correlation values coded as wavelet S.3.3. The chosen wavelet parameter, which is wavelet "S.3.3", can be seen in Figure 4. Then, the chosen wavelet was applied to the well seismic tie process and was evaluated on the seismic cross-section for each line.

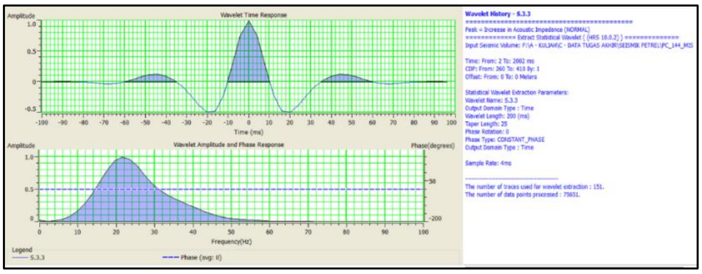


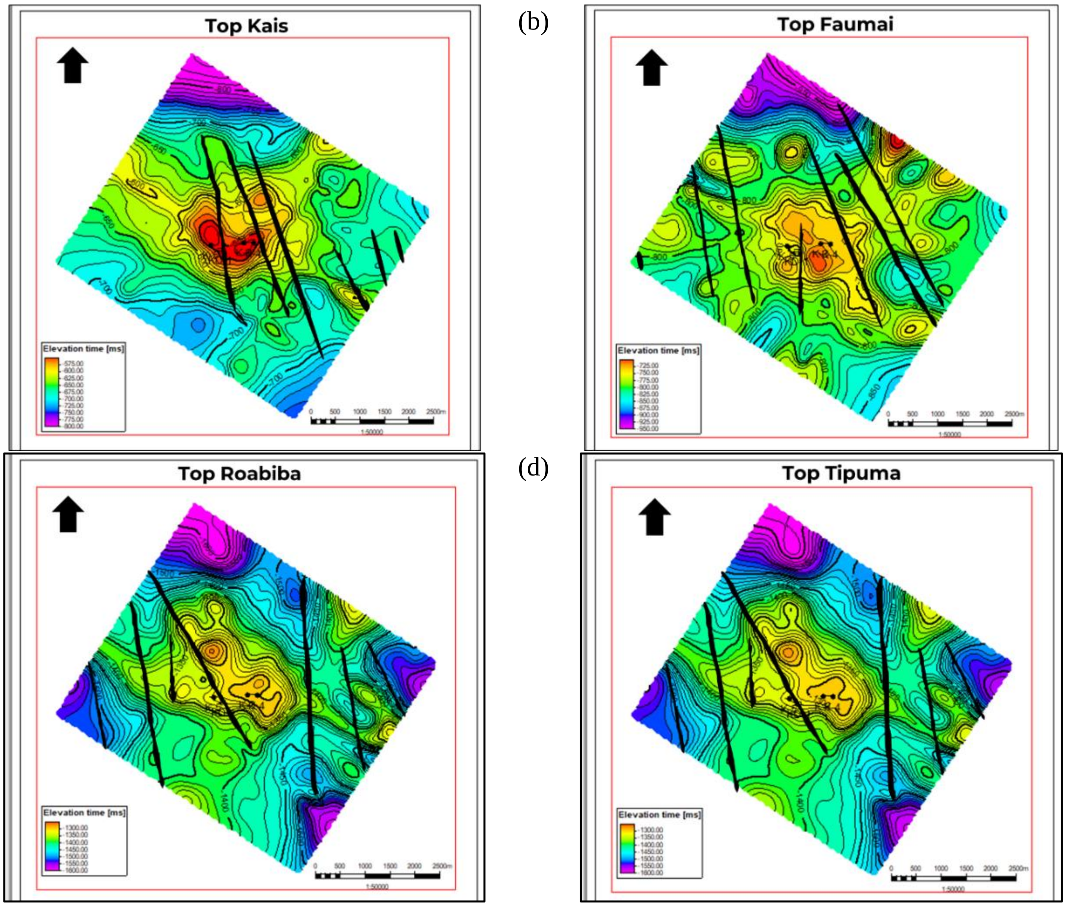
Figure 3. Wavelet S.3.3 parameters

Structural Interpretation

The interpretation process was first done on the wireline log data, the well's structural correlation showed the general structure information such as its layer's boundaries, lithology, and hydrocarbon contacts. Generally, the dominant structure is an eastern ascending pattern. It also confirmed the occurrence of strike-slip faults in the area according to the geological information. These faults had two main roles in the petroleum system, which are as a trap and hydrocarbon migration pathways.

A further interpretation was done to pick the faults and horizons on each of the seismic line data. Fault interpretation was done by connecting the discontinuity points of each reflector to get geological faults, which resulted in sixteen rising faults on all of the seismic lines. It also confirmed the occurrence of the positive flower structure in the area. On the other hand, the horizon interpretation was focused on four targeted zones which are Top Kais, Top Tipuma, Top Roabiba, and Top Faumai. Both of the interpretation results then will be converted into a surface for each of the horizon targets. The final output is time structure maps that can be seen in Figure 4 on each of the targeted tops.

(a) (b)



(c) (d)

Figure 4. Targeted tops time-structure maps (a) Top Kais, (b) Top Faumai, (c) Top Roabiba, (d) Top Tipuma

Domain Conversion

The resulting time-structure maps from the structural interpretation process were still in the time domain, so they had to be converted into the depth domain. The analysis showed that the velocity surface conversion resulted in a better average offset between the well marker's depth and its conversion results depth. The final converted surfaces then were further corrected by eliminating the rest of the offset between the well marker and the depth conversion result. The final conversion output was depth-structure maps that would help for the following processes and the analysis on its own.

Acoustic Impedance (AI) Seismic Inversion

Model-based inversion method was carried out using an initial model for each of the seismic lines. It is also controlled by all of the wells and the interpreted horizons. The pre-inversion analysis showed a great correlation between the initial model and the predicted p-impedance logs with an average correlation of 0.9062 and an average error of 0.4178 across all the wells and seismic line combinations. The seismic inversion was carried out on all of the seismic lines. The resulting AI inversion was then extracted on each of the targeted horizons to get the lateral AI value distribution as can be seen in Figure 5. The AI value range on Top Kais is 20.000-40.000 g.ft/(cm/s) that is highlighted by light blue colors to orange, as for the Roabiba Sandstone AI value range is 36.000-50.000 g.ft/(cm.s) that is highlighted by green to dark orange colors. These high AI value distributions are correlated with the prior analysis result that showed both of these intervals as reservoir zones.

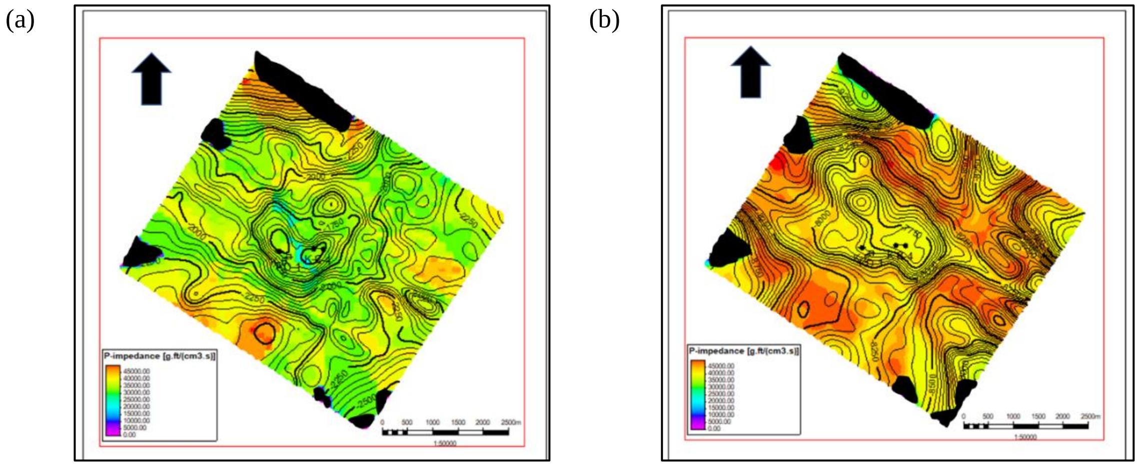


Figure 5. AI distribution map overlaid by depth structure map (a) Top Kais, (b) Top Roabiba

Seismic Multi-Attribute Analysis

Seismic multi-attribute analysis was used to predict porosity value distribution on each of the targeted tops using the combination of several seismic attributes and the AI seismic inversion results. The linear regression method was used to determine the optimal number of attribute combinations that would be validated by its error and correlation value. The result of the analysis process is an average error of 8.9275% and an average correlation value of 0.7413, regarded as an acceptable value the porosity prediction result could be used to identify the porosity distribution on each of the targeted tops.
The porosity prediction distribution can be seen in Figure 6. on Top Kais and Top Roabiba. According to the porosity map, the Top Kais porosity value range is 5-22% and the Top Roabiba porosity value range is 5-25%. The porosity distribution correlated with the prior analysis results confirmed further limestone lithology in the Kais Formation zone and sandstone lithology in the Roabiba Sand interval. It also shows southwest to southeast porosity distribution patterns as well as some porous closure areas. The porosity distribution map comparison between these two methods showed a bit of difference, more importantly in the anomaly occurrence in the middle of the research area of the AI seismic inversion porosity map. According to the prior geological study, the peak closure structure should show a high

AI value as it correlated with high porosity but in truth, it showed otherwise. It is indicated that the anomaly was caused by the high clay content on top of the Kais Formation around the anomaly's area since high clay volume also correlated with low AI value. That is why in this BM Field assessment, the seismic multi-attribute analysis method to predict porosity distribution is needed to be done since the AI inversion resulted in anomaly occurrence. Both of the top targeted zone's porosity is in the range of 5-25% which is bad to good according to Koesoemadinata's classification in 1978 [7].

4. Conclusions

Based on the analysis results can be summarized:

(a) Subsurface geology structure is dominated by dextral strike-slip faults that created the positive flower structure.
(b) The range of AI value distribution is 20.000-40.000 g.ft/(cm.s) on Top Kais and 36.000-50.000 g.ft/(cm.s) on Top Roabiba. With an AI value anomaly occurrence in the middle of the Top Kais Formation, it is indicated to be affected by clay content domination near the top boundary of the Kais Formation. It is also confirmed by its absence on the seismic multi-attribute porosity map.
(c) High AI value correlated with porous zones with the same distribution pattern as the multi-attribute map which is southwest to the southeast. The porosity value result is in the range of 5-25% and geologically more accurate compared to the seismic inversion result.
(d) High-value porosity and AI points are located in the southwest to the southeast dominant pattern which are great potential reservoirs on BM Field.

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Capturing Geo-Hazard and Shallow Reservoir Potential by Acquiring High-Resolution 3D Seismic Survey

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Abstract. In the era of hydrocarbon exploration and development, research to identify subsurface hazards potentials and risks need to be done first as an effort to prevent business failures due to planning errors. In the offshore hydrocarbon exploration survey, drilling hazards must be identified first. Among them are shallow gas, shallow channel, pockmark, and man-made objects buried under or lying on the seabed. Survey method with excellent record resolution is required to identify these hazards as clearly as possible. The seismic method is capable of penetrating under the seabed. However, to produce a clearer cross-section, the seismic method needs to be developed into a High-Resolution survey and uses a three-dimensional (3D) configuration to display the ability to interpret from all sides. Saka Energy Muriah Ltd through PT Mahakarya Geo Survey has successfully conducted a high-resolution 3D (HR3D) Seismic survey in the Suisen Muriah Block, ~92km NNE from Rembang coast to investigate the hydrocarbon potential and subsurface hazards that may exist. While acquiring, the data's condition and quality observed by performing QC onboard processing, we can determine the data's condition and quality when measuring so that the data will be quickly processed and more advanced in onshore-based processing.
Keywords: Geo-hazard, High Resolution 3D Seismic, QC Processing

1. Introduction

In the last few years, there has been an increasing demand for geo-hazards studies and shallow gas exploration. Particular subsurface geo-hazards include shallow hydrocarbons, shallow water flows, faulting to shallow depths, mud volcanoes, and pockmarks, all of which can lead to incompetent sediments and seabed instability [1]. This makes high-resolution seismic a solution to the problem. However, the high-resolution 3D seismic survey (HR3D) application is limited by economic and methodological reasons [2].

Geo-hazards are commonly observed in offshore geophysical surveys. Shallow gas and channel are typical geo-hazards frequently found using seismic methods. The presence of shallow gas is indicated by numerous acoustic anomalies on seismic data, including acoustic turbidity caused by the presence of free gas bubbles within the pore space of sediment, acoustic blanking caused by the absorption of acoustic energy by gas-charged sediment, and enhanced reflections due to acoustic impedance contrast with the surrounding sediment [3]. The most effective approach for a shallow hazard study is to analyze all data types and determine their suitability for application to the assessment of any particular source of hazard. One of the most significant issues with upper section drilling condition assessments is shallow gas, which may be found in the High-Resolution 3D seismic dataset and can be detected effectively. The advantages of high-resolution 3D seismic acquisition are high-frequency data and outstanding vertical resolution [4].

This acquisition uses a high-resolution 3D seismic method in which quality control is carried out by the QC processor during acquisition. The survey was acquired in Suisen Block, Java Sea from 20th –

23rd 2022 August 2022 recorded using MSX Guardian Solid™ streamer that tied up to survey vessel (Nordic Bahari). For quality control on acquisition purposes, seismic data was processed using Globe Claritas v6.6.6 with 2D and 3D processing flows.

2. Data and Methodology

2.1. Seismic Survey

Seismic method is one of the most effective methods for identifying and predicting subsurface lithology and geo-hazard. It plays a crucial role in the discovery of subsurface gas and geo-hazards. The identification marks are mainly the bottom simulating reflectors, velocity, amplitude anomaly, and variation with offset. HR3D seismic surveys utilize a difference source and receiver parameter with conventional 3D seismic survey hence the spatial resolution produced by HR3D survey will be better than conventional 3D seismic survey.

Subsurface gas or geo-hazard detection using the seismic method is seemingly straightforward. It is well known that the presence of shallow gas can be inferred from amplitude anomalies in stacked seismic data. These anomalies result from seismic reflection indicating the presence of shallow gas. However, not all anomalies in the shallow subsurface are related to gas [5].

2.2. Survey Setting

These data were collected around the North East Java Basin, located on Suisen Muriah Block (~92km of NNE Rembang) on the edge of Sundaland, where the basement is a Cretaceous to basal Tertiary melange. The area is geologically complex, and it can be grouped into five tectonic provinces from North to South are Northern slope includes the stable Rembang continental shelf and Randublatung transitional zone, Kendeng trough, the eastern extension of Bogor Trough, a labile deep sea basin, Modern Volcanic Arc Southern slope regional uplift [6].

The stratigraphy in this area represented by the Rembang and Randublatung zones is dominated by stable continental shelf to basinal slope sediments. Stratigraphic and structural analyses by Yulihanto et al. (1995) show four depositional cycles within the Tertiary sediments of this area: Late Oligocene-Early Miocene extensional phase, followed by Early Miocene basin subsidence, Middle Miocene extensional phase, and Upper Miocene Pliocene basin subsidence. It is the possibility that it is composed of mid-late Miocene sedimentary rocks with the composition of the Tawun Formation, Wonocolo Formation, and Bulu Formation [7]. Meanwhile, the reservoirs of biogenic gas in NE Java Basin are from middle Miocene Tawun to early Pliocene Mundu sands and carbonates. Mixed gas occurred by depth-selective accumulation with shallow biogenic and deep thermogenic origin [8].

2.3 Energy Source

Source configuration is the dual source (port and starboard) and number of separation 50 meters (Figure 1(b)). Each source has a single array with four guns and a separation of 2.25 meters (Figure 3). Testing between two volumes was conducted to get better parameters that potentially could create good quality data; hence bubble test by picking the first-time break and bubble period of near field hydrophones attached near the gun was conducted. Gun tests were conducted before the survey using 400in^3 and 220in^3. The volumes of guns for 400in^3 volume mean that each gun will have 100in^3 volume, while 220in^3 is distributed with different volumes of every gun (Figure 3). The gun depth for 400in^3 at 2.5 meters and 200in^3 at 3 meters.

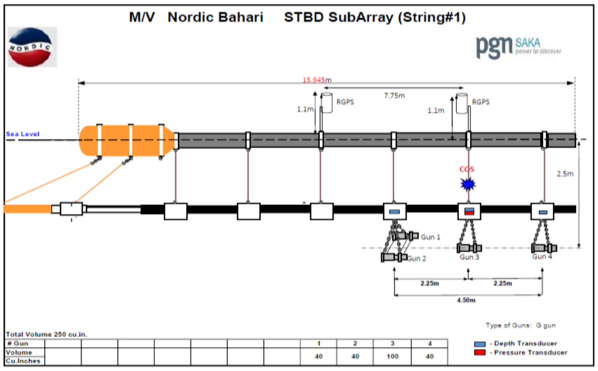


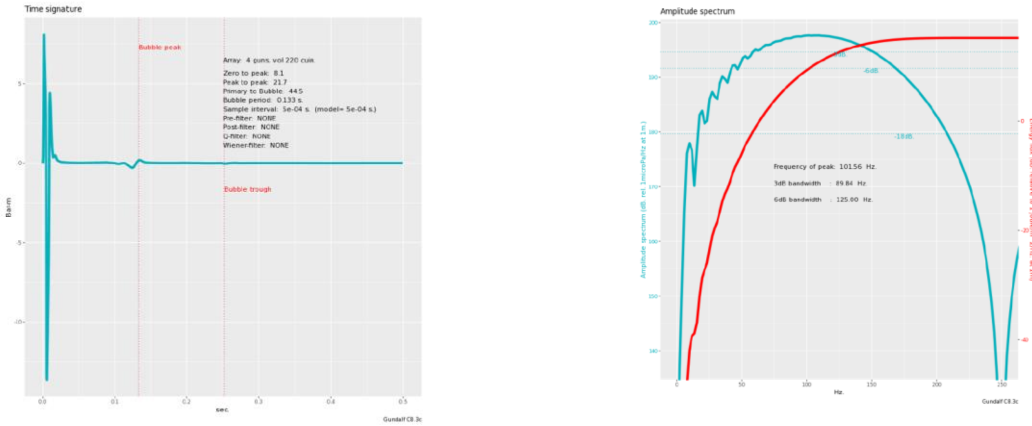
Figure 1. Gun configuration

The average errors for 400in^3 volume are -6.9% for starboard guns and -6.8% for port guns. The negative value here indicates that the calculated gun chamber volume of all guns is below the designed volume. Meanwhile, 220in^3 volume gives an average error of 0.7% for starboard guns and 3.2% for port guns. Because 220in^3 has a significantly lower error than 400in^3 volume, it is chosen for the survey conducted using 220in^3 volume of the gun at 3 meters depth.

Gun modeling was designed using Gundalf with gun volume 220in^3 at 3 meters depth to create a far-field signature (Figure 4), and error bounds stated in Table 1:

Table 1. Error bounds modeled by Gundalf

Number of Guns	4 (220.00 in^3, 3.61 liters)
Peak to peak in bar-m	21.7 +/- 0.5 (2.17 +/- 0.1 MPa, 247 dB re 1muPa. at 1m)
Zero to peak in bar-m	8.1 (0.81 MPa, 238 dB re 1muPa. at 1m)
RMS pressure in bar-m (full window)	1.08 (0.108 MPa, 221 dB re 1muPa. at 1m)
Primary to bubble (peak to peak)	44.5 +/- 1.6
Bubble period (s)	0.133 +/- 0.004
Maximum spectral ripple (dB)	26 (10 - 70 Hz)
Maximum spectral value (dB)	196 (10 - 70 Hz)
Average spectral value (dB)	189 (10 - 70 Hz)
Total acoustic energy (Joules)	4170.2
Total acoustic efficiency (%)	8.4
Maximum model bandwidth (Hz)	0 - 1024

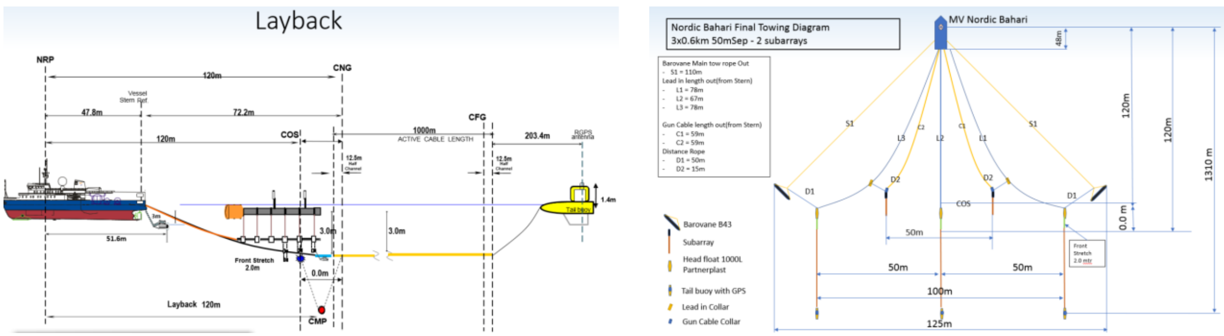


(a) (b)

Figure 2. (a) Far field signature of guns with 220in^3 volume at 3 meters depth; (b) The amplitude spectrum of designed far field signature.

2.4 Receiver Array, Geometry and Recording Parameters

The MSX Guardian Solid™ streamer is the fundamental component of the receiver array. The streamers were built with a group spacing of 12.5 meters and 14 hydrophones per group. The number of streamers deployed was three cables with each streamer consisting of 80 channels (total of 240 channels) with lengths of 1000 meters and 50 meters separating each cable at 3 meters and 4 meters depth as receivers (Figure 1). Line spacing was 50 meters without overlap between adjacent passes. The survey ran with two headings of 125.3° and 305.3°. This direction was considered suitable for feather matching and worked very well with the majority of the survey with a maximum feather angle was 18°, and an average feather angle was 4° to the West (Figure 2(a)).



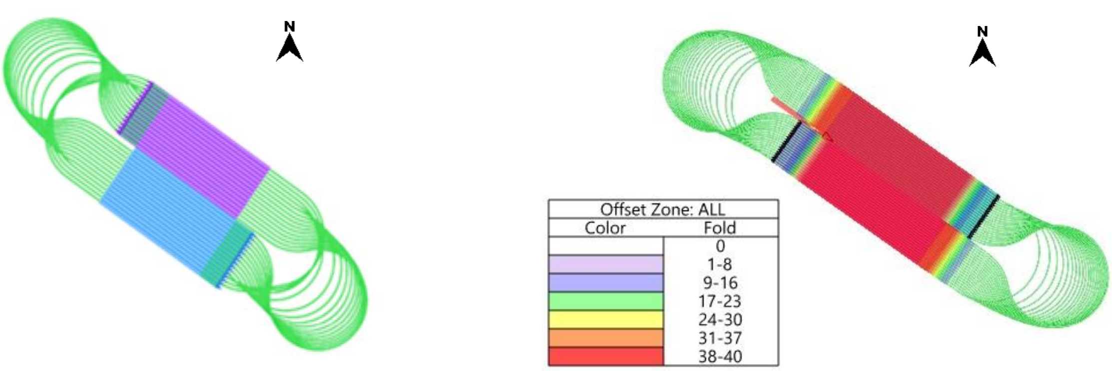
(a) (b)

Figure 3. Vessel layout diagram (a) side view; (b) top view.

The geometry setting is not related to the seismic data, only using the existing marine geometry module by entering the seismic survey configuration information that refers to the observer log. Furthermore, the bin size is calculated using equation (1):

$$Bin\ Size\ Aquisition = \frac{Receiver\ Interval\ (RI)}{2}\ x\ \frac{Source\ Separation\ (SI)}{2} \quad (1)$$

As a result, the bin size is 6.25 meters x 25 meters, and we got a number-fold coverage of 40 (Figure 2(b)). The recording system was configured with a record length of 2.048 seconds and a sample rate of 1 millisecond. The digitizer used a low-cut analog filter (2Hz/6db/oct) and a hi-cut filter (412Hz/264db/oct) through the recording software. Target vessel speed during acquisitions was 3.2 knot over-ground. The data were recorded according to the Society of Exploration Geophysicist (SEG) with SEG-D (8058) format and normal polarity.



(a) (b)

Figure 4. (a) Estimated shooting plan. The blue line has a heading 125.3˚ and the purple line heading is 305.3˚; (b) Fold coverage map