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Full paper

Applying the Horizon Based Tomography Method to Update Interval Velocity Model, Identify The Structure of Pre-Stack Depth Migration 3D and Estimate The Hydrocarbon Reserve In SBI Field of North West Java Basin

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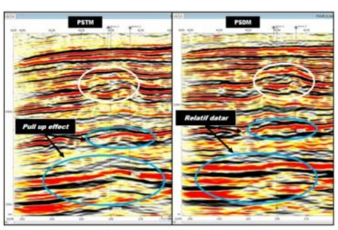
Graphical abstract



Comparison of PSTM and PSDM section

Abstract

Seismic data processing is one of the three stages in the seismic method that has an important role in the exploration of oil and gas. Without good data processing, it is impossible to get seismic image cross section for good interpretation. A research using seismic data processing was done to update the velocity model by horizon based tomography method in SBI Field, North West Java Basin. This method reduces error of seismic wave travel time through the analyzed horizon because the existence velocity of high lateral variation in research area. There are three parameters used to determine the accuracy of the resulting interval velocity model, namely, flat depth gathers, semblance residual moveout that coincides with the axis zero residual moveout, and the correspondence between image depth (horizon) with wells marker (well seismic tie). Pre Stack Depth Migration (PSDM) form interval velocity model and updating using horizon-based tomography method gives better imaging of under-surfaced structure results than PSDM before using tomography. There are three faults found in the research area, two normal faults have southwest-northeast strike and the other has northwest-southeast strike. The thickness of reservoir in SBI field, North West Java Basin, is predicted between 71 to 175 meters and the hydrocarbon (oil) reserve is predicted about $1{,}134 \times 10^6$ STB with 22.6% porosity and 70.7% water saturation.

Keywords: Horizon based tomography method; interval velocity model; pre-stack depth migration (PSDM); hydrocarbon reserve estimation

1.0 INTRODUCTION

Seismic data processing is one of the three stages (data acquisition, processing, and interpretation) in the seismic method which plays an important role in oil and gas exploration. The goal of seismic data processing is increasing the cross-sectional images for getting better at every stage. The results of the cross-sectional image are expected to further facilitate the interpretation.

Seismic standards imaging methods generally use two processing stages, namely the stage of determining the velocity model and reconstruction phase reflector through migration. In relatively homogeneous structure horizontally, standard processing is able to produce images that correspond to the actual geological conditions. However, in complex structure such as when there is a salt dome or carbonate reef structures that have high heterogeneity horizontally, the default processing will then fail [1]. Standards processing include sorting the common mid-point (CMP), velocity analysis, normal move out correction (NMO) or dip move out (DMO), and migration in the time domain or what is commonly known as Pre-Stack Time Migration (PSTM) [2].

Chang *et al*. developed tomography method to refine the interval velocity model is using as input for Pre-Stack Depth Migration (PSDM). Tomography is used due to the application of the initial interval velocity model is less accurate [3]. Tomography algorithm consists of a horizon-based tomography method and grid-based tomography. Seismic tomography analysis is an inversion process that departed from the observed wave propagation time is then searched the cause, which can include porosity distribution, the velocity distribution or the presence of both vertical and lateral fracture [4]. The horizon based tomography will fix the error travel time of seismic waves along the horizon [5]. An improvement in the error of the seismic wave propagation time, then there will be an improvement on the depth error. These improvements expected to provide correct information about the subsurface velocity. This method uses the input residual depth moveout analysis.

Information from geological data indicates that the SBI field of North West Java basin are complex structures, it is characterized by the presence of reef carbonate [6]. In such a complex structure this would lead to high lateral velocity variations [7]. The presence of lateral velocity variations will cause the deflection of a beam (ray bending) when passing through the boundaries of the layer so that time wave propagation is begining not hyperbolic. High lateral velocity variations in research area cause migration in the time domain (PSTM), using RMS velocity model is inaccurate because it is sensitive to the variation of vertical velocity alone. Therefore, it is required in the domain depth migration (PSDM) to use the interval velocity model that sensitive to the variation of the vertical and horizontal velocity. However, the PSDM needs an accurate interval velocity model. One way to generate an accurate interval velocity model is to make the process of residual depth moveout analysis and horizon-based tomography.

It has been done a research on the seismic data processing to update the velocity model by horizon based tomography method in SBI Field, North West Java Basin. The purpose of this research is: (1) to create and refine interval velocity model with analysis residual depth moveout horizon-based tomography, (2) to get the actual geological model and prove the accuracy between results of time domain 3D image PSTM and depth domain 3D image PSDM, (3) to compare the results of PSDM before and after tomography process, (4) to identify fault structures of the PSDM results tomography process, (5) to determine reservoir thickness distribution and estimating hydrocarbon reserves

2.0 EXPERIMENTAL

2.1 Research Tools

In this research, there are two main devices, (1) hardware, with details the Central Processing Unit: RedHat Enterprise Linux AS 5.0, two 24-inch monitors, servers: SGI Altix 450/SuSe Linux Enterprise Server 9.0, 32 GB, 32 X 2.6 GHz Processor, network: Gigabit 1 Gb / s, and (2) software used is Paradigm, product: Seismic Processing and Imaging, with details of: software GeoDepth velocity Modeling (Epos 41), GeoDepth (to undertake the manufacture of RMS velocity maps and 3D models manufacture and refine interval velocity model), software Migrations GeoDepth to run the 3D PSTM and PSDM (Fermat/Eikonal) to run the process PSDM), and Software 3D GeoDepth Tomograpy (to perform tomography process)

2.2 Seismic Data

There are two types of data used are seismic data and well data. The seismic data consist of CDP Gathers and RMS velocity, well data include: sonic log, density log, resistivity log, gamma ray log (GR), and neutron logs. The log data used to calculate the estimated hydrocarbon reserves.

2.3 Data processing

There are four step in data processing, namely (1) to create 3D model RMS velocity maps as shown in Figure 1, (2) to create and refine interval velocity model as shown in Figure 2, (3) to identify fault structures from final PSDM result, and (4) Calculation hydrocarbon reserves. Stages calculation of hydrocarbon reserves is as follows:

2.3.1 Calculation of Porosity Values (ϕ)

Value of porosity in the reservoir layer is the combined value of the porosity from two different curves, that is the density porosity (ϕ_D), which is the result of the calculation curve RHOB and neutron porosity (ϕ_N), read from NPHI curve, calculated by Equations 1 and 2:

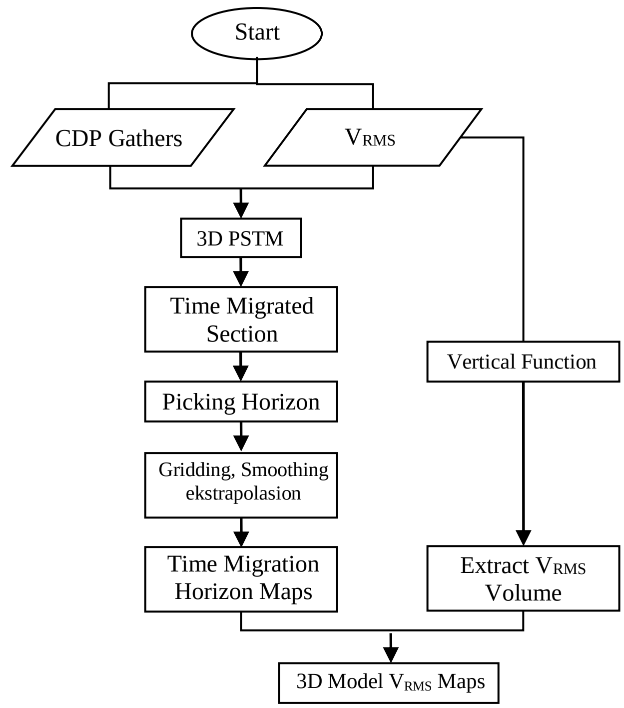


Figure 1 Flow diagram to create 3D model RMS velocity maps

$$\phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \qquad (1)$$

$$\phi_{DN} = \sqrt{\frac{{\phi_D}^2 + {\phi_N}^2}{2}} \qquad (2)$$

where ϕ_D is the density porosity, ρ_{ma} density matrix rocks (sandstones value to 2.65, limestone 2.71, and dolomite 2.87), ρ_b is the bulk density of the rock, from the reading of the log curve RHOB, ρ_f is the density of liquid drilling mud (for value fresh mud is 1.0 and the value salt mud is 1.1), ϕ_N is the neutron porosity.

The value effective porosity calculated with the Equation 3 after first calculated shale volume (Equation 4) contained in the reservoir.

$$\phi = \phi_{DN} \times (1 - V_{sh}) \qquad (3)$$

where ϕ_{DN} is the neutron density porosity, V_{sh} is shale volume, dan ϕ is the effective porosity or so-called porosity only

2.3.2 Calculation of Shale Volume (V_{sh})

Volume of shale (V_{sh}) is the content of the shale in formation, calculated by Equation 4.

$$V_{sh} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (4)$$

where GR_{log} is the value of the gamma ray log data, GR_{max} is the maximum value of gamma ray, and GR_{min} is the minimum value of gamma rays.

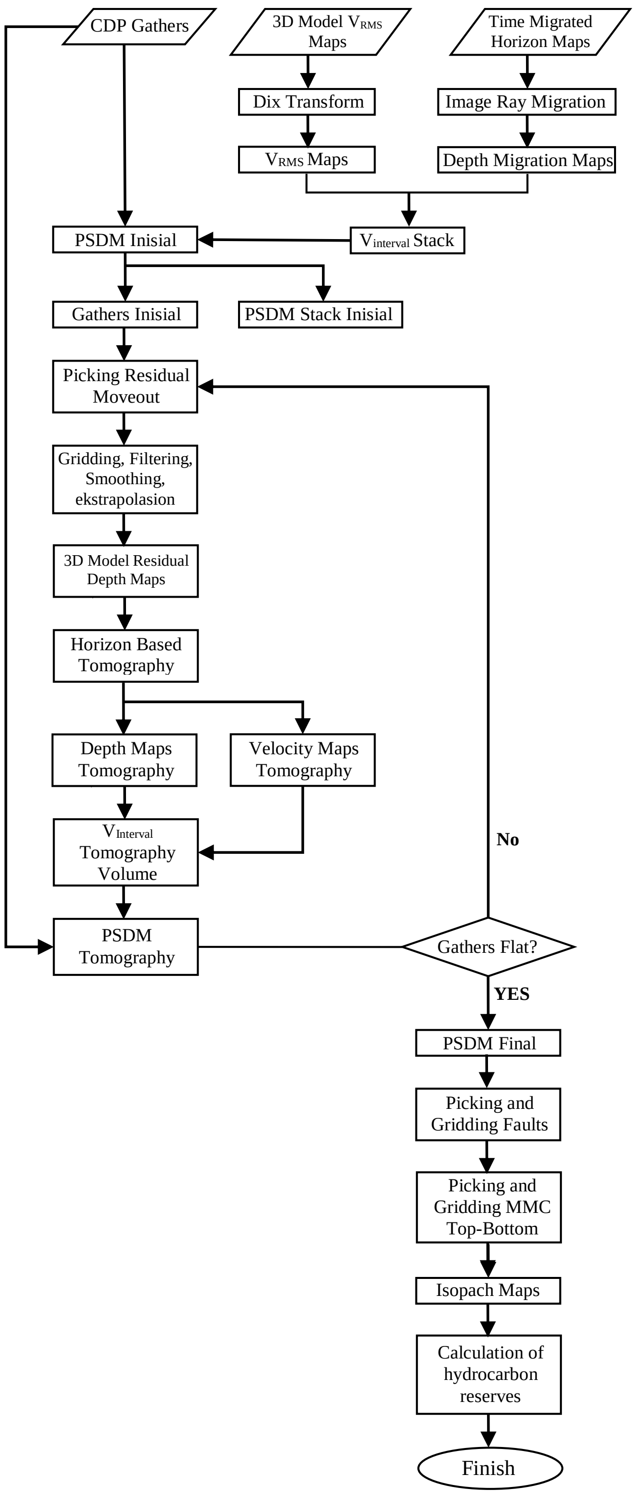


Figure 2 Flow diagram to create and refine the interval velocity model and identify fault structures from final PSDM result

2.3.3 Calculation of Water Saturation (S_w)

Water saturation is the ratio of the pore volume occupied water of the total volume porosity. The equation used is Archie Equation [8],

$$F = \frac{a}{\phi^m} \quad (5)$$

$$S_w = \sqrt{\frac{F \times R_W}{R_t}} \quad (6)$$

where F is the formation resistivity factor, a is the lithology coefficient (limestone $a = 1$, sandstones $a = 0{,}65$), ϕ_{DN} is the neutron density porosity, m is the cementation factor (limestones $m = 2$, sandstones $m = 2{,}15$), F is the formation factor, R_W is the formation water resistivity, and R_t is the formation resistivity, read from the resistivity curve[9].

2.3.4 Approach Calculation Method of Bulk Volume (V_b)

Reservoir volume calculations performed by using equation trapezoidal or pyramidal, which affected the ratio of the area between one contours with other. Comparison between the area above and below the area known as the ratio defined in Equation 7.

$$Rasio = \frac{A_{n+1}}{A_n} \quad (7)$$

where A_n is the area covered by the contour n (m^2), and A_{n+1} is the area covered by the contour $n + 1$ (m^2).

Approach method to calculation of the bulk volume (V_b) reservoir from isopach maps are: (1) pyramidal method, this method is used when the value of the ratio between successive contours is less than or equal to 0.5 or $\frac{A_{n+1}}{A_n} < 0.5$. Equation 8 is used to calculate the bult volume.

$$V_b = \frac{h}{3}\left[A_n + A_{n+1} + \sqrt{A_n\,A_{n+1}}\right] \quad (8)$$

(2) trapezoidal method, this method is used when the value of the ratio between successive contours over 0.5 or $\frac{A_{n+1}}{A_n} > 0.5$. Equation 9 is used to calculate the bult volume.

$$V_b = \frac{h}{2}[A_n + A_{n+1}] \quad (9)$$

where V_b is bulk volume (acre.ft), A_n is surrounded contour area to-*n* (acre), A_{n+1} is the area surrounded by the contour to *n+1* (acre), and h is the isopach contour interval (feet).

2.3.5 Determination the Hydrocarbon Reserves with Volumetric Method

In this method, the calculation is based on the volume equation, the data supporting to calculate of these reserves are porosity and water saturation, the equation used is divided into: (1) Initial Oil In Place (IOIP), calculates the oil content in formation by using:

$$IOIP = \frac{V_b \times \phi \times (1 - S_w)}{Boi} \times 7758 \quad (10)$$

where IOIP is Initial Oil In Place (STB, Stock Tank Barrels), 7758 is the conversion factor from barrels to acre.ft, V_b is the bulk volume of the reservoir (acre.ft), ϕ is the porosity (%), S_w is water saturation, and Boi is the oil formation volume factor (usually 1,163), (2) Initial Gas In Place (IGIP), calculate gas content in formation by using:

$$IGIP = \frac{V_b \times \phi \times (1 - S_w)}{Bgi} \times 43560 \qquad (11)$$

with IGIP is Initial Gas In Place (SCF, Standard Cubic Feet), 43560 is a conversion factor from acre.ft to cubik.ft, V_b is the bulk reservoir volume (acre.ft), ϕ is the porosity, Bgi is the gas formation volume factor (SCF / cuft).

■3.0 RESULTS AND DISCUSSION

3.1 Analysis of Interval Velocity Model

There are 3 types of velocity models in this research, namely: (1) RMS velocity model, which is the result from the map time migrated horizon and RMS velocity maps, (2) interval velocity model before tomography process, which is the result from Dix Transforms interval velocity map (converted from RMS velocity maps into interval velocity map by Dix Transform method) and depth maps (the conversion from time migrated horizon maps into depth map by Image Ray Migration method), and (3) interval velocity model after tomography, which is the result from interval map results of tomography method and depth maps of tomography results (picking residual moveout produce residual moveout maps, then as it input for tomography process). Comparison of the three velocity models can be seen in Figure 3, 4, and 5.

Interval velocity model (Figure 4 and Figure 5) show better picture to present interval velocity model variation of the subsurface geology and compared with the RMS velocity model (Figure 3). RMS velocity model is sensitive only to the geological model which has only vertical velocity variations, while the geological model that has high velocity variation both vertically and horizontally, then this velocity model is less accurate to used, the solution is to use interval velocity model is sensitive to both.

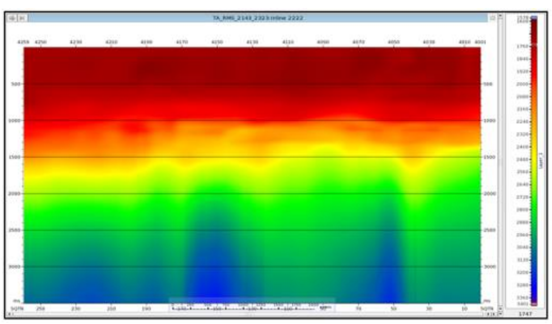


Figure 3 RMS velocity model

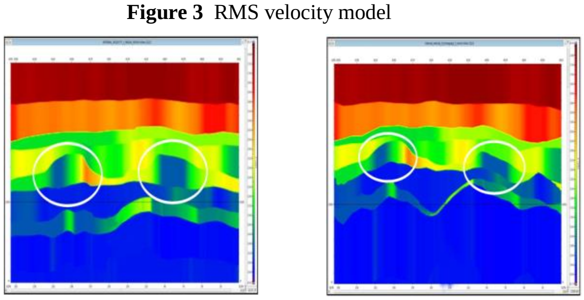


Figure 4 Interval velocity model results from dix transform, before tomography (left) and after tomography process (right)

At interval velocity model after tomography process (Figure 4) shows the change velocity in direction of the vertical and lateral velocity more clearly than before tomography (white circles), it can be seen that the lateral velocity variation is quite high (white circle). The blue color flanked by green color indicates that different structure exists between them. The blue color indicates is higher velocity than green color. Based on the geological information, blue color is reef carbonate formation that lies between parigi bottom and pre-parigi. Vertical and lateral velocity variations in interval velocity model due to lithology variations. Lithology structure of the target layer composed by reef (reef carbonate) and uneven distribution. At the bottom structure composed of limestone massive, it is more growing up and more porous. This suggests that different lithology makes differences in physical properties which cause variations of velocity in interval velocity model.

3.2 Comparison between PSTM and PSDM Final Iteration

Comparison between PSTM cross section and PSDM cross section at same inline 2222, shown in Figure 5. In PSTM cross-section inline 2222 shows geometry reflector patterns under carbonate reef layer (green circle) which appears to rise, as shaped layer with a specific slope (dip). The appearance of reef carbonate in seismic cross sections marked with a white circle. The reflector looks lifted is feared that a pull-up-effect because high velocity layer above it and this can lead to errors in interpretation.

Imaging results using Kirchhoff PSDM method as shown in Figure 5 on the same inline with previous PSTM cross section inline 2222, showed that reflector geometry under reef carbonate have seen flat and not seen reflectors which attracted to top. The pull up effect form the slope layer in PSTM due appears high velocity when waves pass through layers of carbonate, the surrounding area has a lower lateral velocity, so the layer below to be uplifted. Through this PSDM obtainable seismic section more present actual geological model. PSDM algorithm used is able to prevent assumptions and simplifications that cause errors in the PSTM position. Not only reflector position is accurate, but also capable resulting sustainability reflector or no sustainability reflector caused by a structure so PSDM imaging results is better used in the identification of geological structures.

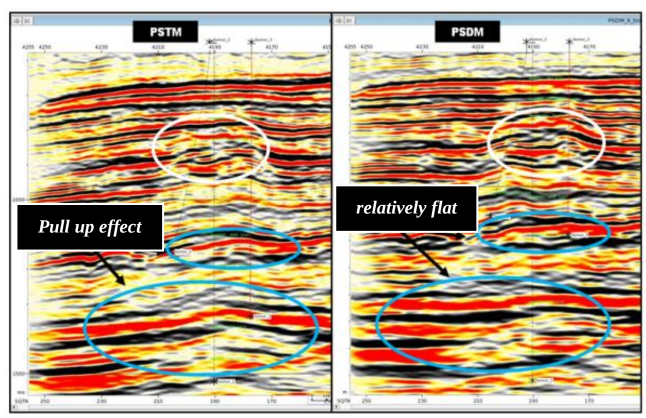


Figure 5 (a) PSTM seismic section on inline 2222, (b) PSDM final cross-section (results iterations to 5) on inline 2222, the target research area with wells and marker as well as control

3.3 PSDM Comparison Before and After Tomography

Comparison PSDM cross section on inline 2222 before tomography (velocity model resulting Dix Transform) and after tomography (interval velocity model resulting iteration tomography 1 to 5) are shown in Figure 6.

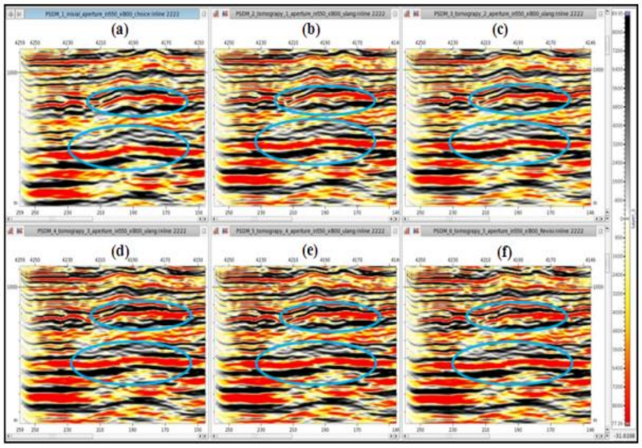


Figure 6 Magnification PSDM section on inline 2222 research target area, (a) prior to tomography, (b) after tomography iterations to 1, (c) after tomography iteration 2, (d) after tomography iteration 3, (e) after tomography iterations to 4, (f) after tomography iterations to 5

In PSDM cross-sectional before tomographic process, there is visible pull up effect (pull up reflector, green circle) although reflector dip smaller than pull up effect of PSTM cross-section, it is indicating the presence high velocity from reef carbonate which is located above the target of research. However, after tomography process, pull up effect gradually decreases proportional to the number of iterations performed. Reflector below of reef carbonate looks relatively flat after tomography until the 5th iteration (green circle), so for next iteration, it is not expected to give a significant effect on change in dip reflector. Needs to be done next iteration or not depends on three parameters tomography, namely: (1) depth Gathers already flat or not, (2) semblance residual moveout coincide with the axis that has zero residual moveout or not, and (3) appropriate or not the resulting of depth image (horizon) with marker well (well seismic tie.)

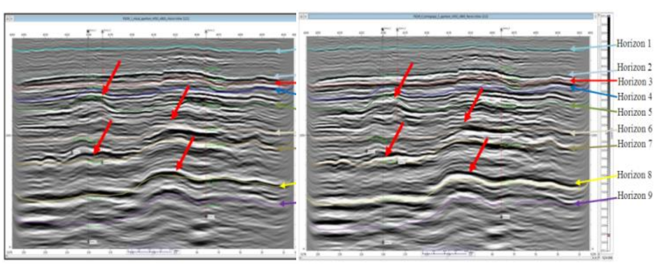


Figure 7 Depth image PSDM, from initial interval velocity model (left), is not suitable represent the horizon, visible horizon is still deviate from reflector (indicated by red arrows) (left)**.** Depth image PSDM, from final interval velocity model has been represented in accordance with the horizon (indicated by red arrows) (right)

Analysis of depth image PSDM along with marker wll before and after tomography are shown in Figure 7. The discrepancy between depth image maps with reflector associated with the boundary layer on depth image can be seen when both are displayed in one section (overlay). Before tomography process, boundary layer on interval velocity model will deviate from reflekor (boundary layer) which represented on resulting *depth image* (red arrows in Figure 7), whereas after tomography process, depth image horizon has been represented the formation of boundary layers.

3.4 Fault Structure in Field SBI

Identification of fault structures done from final PSDM cross-section (result iteration 5). There are three fault has been identified on seismic section in SBI field, North West Java Basin. Figure 8 displays fault with seismic data in 3D canvas. Determination of three fault based on fault components in general ie fault plane, strike fault, slope of fault, hanging wall, foot wall, net slip (includes strike-slip and dip-slip).

The blue color in Figure 8 is the fault plane which includes type of normal faults. This normal fault has major strike fault with southwest-northeast direction. Slope fault estimated at 65^o and hanging wall and foot wall of fault shown in Figure 13. Slip value estimated at around 73 meters. Part of net slip, ie strike slip and dip slip are difficult to identify. The red color, fault plane which includes type of normal faults, have strike direction southwest-northeast, same with major fault. This fault is included in minor fault follows the major fault. The slope fault estimated at 75^o, much steeper than major fault. Net slip value estimated at around 10 meters. The Purple color, normal fault plane, has strike northwest-southeast direction, as opposed major strike fault. This fault also included in minor fault with slope fault estimated at 75^o. Net slip value estimated at around 10 meters.

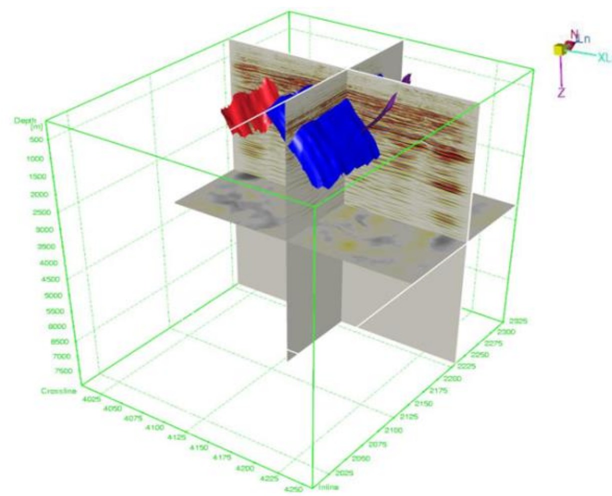


Figure 8 Three faults were identified in reseach area, SBI field, North West Java basin. The third fault included normal faults)

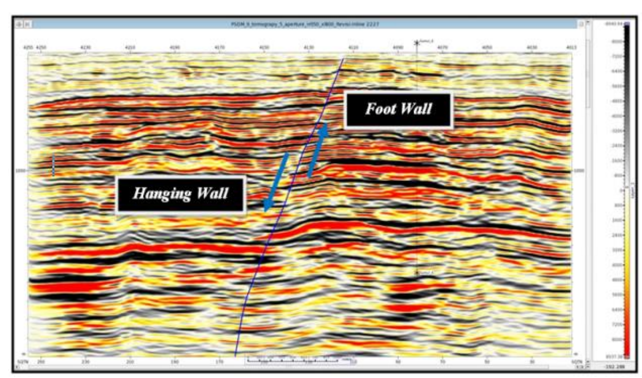


Figure 9 The appearance of hanging wall and foot wall in normal fault (blue) at final PSDM section

3.5 Thickness Reservoir Distribution and Large Hydrocarbon Reserves in SBI Field

The resulting gross isopach map shown in Figure 10. Based scale on the map can be estimated reservoir thickness ranges from 71 meters to 175 meters. The red color indicates that reservoir thickness about 71 meters to 104 meters, the yellow color indicates reservoir thickness about 105 meters to 124 meters, green color indicates reservoir thickness about 125 meters to 156 meters, and blue color indicates reservoir thickness in SBI field about 157 meters to 175 meters.

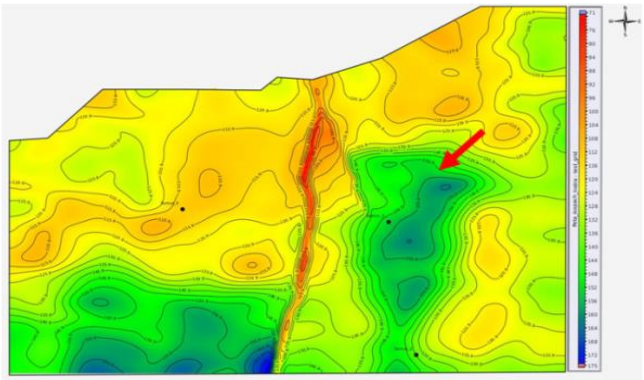


Figure 10 Gross isopach maps, depth maps iso results grid structure over the depth map layer MMC and MMC under a layer structure

Based appearance isopach contours on the map, the part of reservoir contain hydrocarbon is designated red arrows. It can be seen from shape contour and closur contour resembles like container of hydrocarbons. This proved to wells 1, 2 and 3 in areas suspected reservoir containing hydrocarbons (oil) which has approximately thickness around 150.9 meters and depth around 1216 meters to 1247 meters.

The results of the calculations have been done obtained of porosity is 22.6% and water saturation is 70.7%. If comparing the porosity value with the criteria porosity made by Koesoemadinata, the resulting porosity values in SBI field North West Java Basin have an excellent criteria, meaning the reservoir rocks the form carbonate (limestones) has ability to store liquid (hydrocarbons) very well [10].

The large reservoir volumes calculated from isopach maps were thought contain hydrocarbons based on shape contour and closure contours on map. The first step is to determine extent of reservoir using manual method (using millimeter paper). The area enclosed contour n with manual calculations obtained $A_n = 945.178{,}40\ m^2 = 233{,}558$ acre and the area enclosed contour n+1, $A_{n+1} = 366.256{,}63\ m^2$ = 90,503 acre, so from both area obtained ratio between wide area covered contour n and area covered contour $n+1$ is 0.388. Value of this ratio, the approach in calculation of bulk volume using pyramidal method because $\frac{A_{n+1}}{A_n} < 0.5$. Based on calculation, reservoir volume 2,567.104 acre.ft.

Hydrocarbon reserves in SBI field of North West Java Basin is around 1,134 x 106 STB (Stock Tank Barrels). Hydrocarbon reserves of these are pure hydrocarbons, meaning that only contains oil, because from calculations have been separated between water-oil (OWC) and oil-gas (OGC). This separation based on closure contour and log data (the correlation between gamma ray log, resistivity log, density log, neutron log, and sonic log).

4.0 CONCLUSION

In this study, the interval velocity model generated by horizon-based tomography is able to make refinement interval velocity model parameters, namely velocity layer and depth as evidenced flat depth gathers, semblance residual moveout coincide with the axis has zero residual movout, and the correspondence between image depth (horizon) with marker wells (well seismic tie). Pre Stack Depth Migration (PSDM) form interval velocity model and updating using horizon-based tomography method give better imaging and under-surfaced structure results than PSDM before using tomography. There are three faults found in research area, two normal faults have southwest-northeast strike and the other has northwest-southeast strike. The thickness of reservoir in SBI field, North West Java Basin, is predicted about 71 meter to 175 meter and the hydrocarbon (oil) reserve is predicted about $1{,}134 \times 10^6$ STB with porosity is 22,6% and water saturation is 70,7%.

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