RESERVOIR CHARACTERIZATION USING SEISMIC ATTRIBUTES AND SEISMIC INVERSION OF GLOBIGERINA LIMESTONE RESERVOIR, MADURA STRAIT, INDONESIA

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Abstract

To characterize the reservoir in the subsurface, an integration of 3D seismic data and well data is very powerful as it can reveal the lateral and vertical distribution of particular characteristics of the reservoir. This study focuses on the Pliocene age, Mundu Formation in Madura Strait, Indonesia. The reservoir is a bioclastic limestone which is mainly composed of Globigerina planktonic foraminifera tests. This formation has limited producing analogues outside the North East Java Basin which makes this reservoir quite unique. Moreover, there is no published work that discusses in depth about reservoir characterization using seismic attributes and inversion analysis plus the analysis of thinning and thickening of this type of reservoir. The uniqueness of the reservoir is revealed by horizons mapping, analyzing the seismic attributes and inversion analysis. Horizons mapping suggests that the thickness of the reservoir is largely influenced by the uncon-formity surface on its top and base. The analyses of the seismic attributes and inversion depict various characteristics such as fracture potential on the reservoir, predicted hydrocarbon and porosity distribution within the reservoir. Thus, by integration of these various analyses, it is expected that this study can be used for better delineation of the reservoir quality in the study area.

Keywords: Mundu Formation, Seismic Attributes, Seismic Inversion

1. Introduction

The study area (Figure 1) is located within the southern part of North East Java Basin in Madura Strait, one of the most prolific hydrocarbon producers in Indonesia. Within the study area, three wells penetrate the Oyong Field that contains reservoir from Pliocene age, Mundu Formation. This is the only reservoir unit in the study area. The reservoir is a bioclastic limestone which is mainly composed by Globigerina planktonic foraminifera tests. In terms of the quality, this reservoir provides enormous porosity and permeability values that contain oil and gas column.

According to Bransden and Matthews, (1992), Satyana, et al., (2004), and Triyana, et al., (2007), the Mundu formation was deposited concurrently with a period of intense Neogene compression and episodic uplift. A complex interaction of structure and stratigraphy is anticipated which would have an impact on the thickness of the reservoir in the study area. Moreover, the active tectonics during this time potentially could have led to formation of fractures after the unit was deposited.

There are two papers that are related with the study area. First, Sutadiwiria and Prasetyo (2006) discussed reducing the uncertainty of the plan of development for Oyong Field. There is a minor discussion about integration of acoustic impedance analysis with well data to predict the facies, but they did not state what kind of inversion that has been done. Meanwhile, in Iriska, et al., (2010), they discussed the early production from the Mundu Formation.

Hence, this paper analyzes the thinning and thickening of the reservoir and its related causes by mapping seismic horizons. Furthermore, seismic data are used extensively to characterize the reservoir by using attributes and the inverted volume. There are no previously published papers discussing in detail this unique formation.

2. Data Analysis

2.1. Rock Physics

Rock physics were assessed within the zone of the interest, from middle part of Paciran

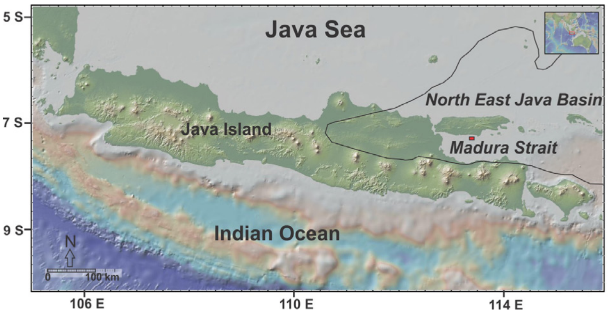

Figure 1. Location of the study area (http://www.geomapapp.org)

Formation through Mundu Formation (reservoir) to the upper part of Wonocolo Formation. Density, compressional sonic and acoustic impedance log versus depth was assessed (Figure 2).

Rock physics analysis of these logs, especially the acoustic impedance log, was used to predict how the rock formations behave on seismic and also will be used as the basis for the colored inversion interpretation.

From the lower part of Paciran Formation passing through the upper part of Mundu Formation, the density value decreases due to the gas effect whereas the sonic log values slightly increase. Internally within Mundu, the density and compressional sonic value tend to increase as it progresses from gas to oil to water

The occurrence of hydrocarbon in the reservoir, especially gas, lowers the density and the sonic value in the wells (Oyong-1 and 2).

The better porosity value coincides with the gas at the top of the reservoir. Then the porosity decreases toward the base of the reservoir where the poorer reservoir is occupied by water. Within the wet zone of the reservoir the porosity content also mimics the acoustic impedance changes. The decreasing porosity (tighter reservoir) is also characterized by an increase in acoustic impedance and vice versa. Thus, it is interpreted that the porosity content within the reservoir also follows the trend of acoustic impedance log. It can be assumed that there is linear relationship between porosity and acoustic impedance log.

2.2. Horizon and Fault Interpretation

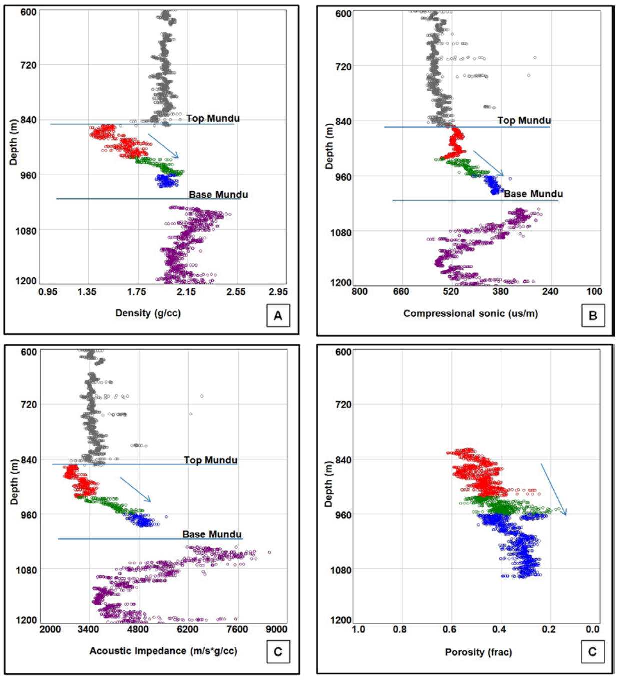

Figure 2. Rock physics analysis of density (A), sonic (B), acoustic impedance (C) and porosity log (D)

Five horizons were mapped, from bottom to top: 1) Base Mundu, 2) Intra Mundu, 3) Top Mundu, 4) Intra Paciran 2 and 5) Intra Paciran 1

Base Mundu horizon (light green colored line in Figure 3) is marked by the truncation of the reflector below, downlap and onlap at its upper side of the surface. Moreover, in some areas this surface shows a base of channel-like shapes. Thus, Base Mundu horizon is interpreted as the Late Miocene unconformity in the study area that separates Mundu Sequence and Wonocolo Sequence as shown in Figure 2.

Intra Mundu horizon (gold colored line Figure 3) in the northern to the center part of the study area is characterized by the truncation at lower part with minor onlap and downlap at the top of the surface. In other parts of the study area, two conformable successions are separated by this surface. Moreover, based on the rock physics analysis as previously described, the upper part in Mundu Formation represents the best reservoir with higher porosity value than the lower part which is interpreted to be included within this interval.

Top Mundu (blue colored line in Figure 3) is characterized by onlap and minor downlap at the top of the surface whereas at the base of the surface some truncation of the lower reflector occurs. Thus, Top Mundu is also considered as an unconformity surface that separates the Paciran Formation above with the Mundu Formation below. The pick of the Top Mundu changes from trough to peak amplitude (phase change) from the higher picks of Top Mundu at the well locations to structurally lower picks along the horizon. This is due to the acoustic impedance contrast of Mundu to Paciran changing from a gas filled Mundu reservoir at the structurally higher level to a water filled Mundu section.

Intra Paciran 2 (red colored line in Figure 3) overlies the heavily faulted, higher-amplitude unit with the less-faulted and lower-amplitude reflector above. Above this surface, the reflectors are mainly conformable with some onlap to the surface. Below the surface, the reflectors are mostly conformable with some truncation.

Intra Paciran 1 (cyan colored line in Figure 3) is marked by continuous and relatively moderately strong trough reflector that covers the whole study area. The surface also is marked by reflector terminations such as onlap on its upper surface and also truncation below the surface.

Normal faults are encountered in all intervals within the zone of interest. These normal faults have relatively east-west and north-south trends. The thrust faults that are responsible for forming the anticline are located deeper far below the zone of interest.

On the seismic section (Figure 3), some faults do not penetrate both Mundu Formation and Paciran Formation. The discontinued faults trend north - south and dip either to the east or west. These faults also have short fault plane and mainly occur within the Paciran Formation

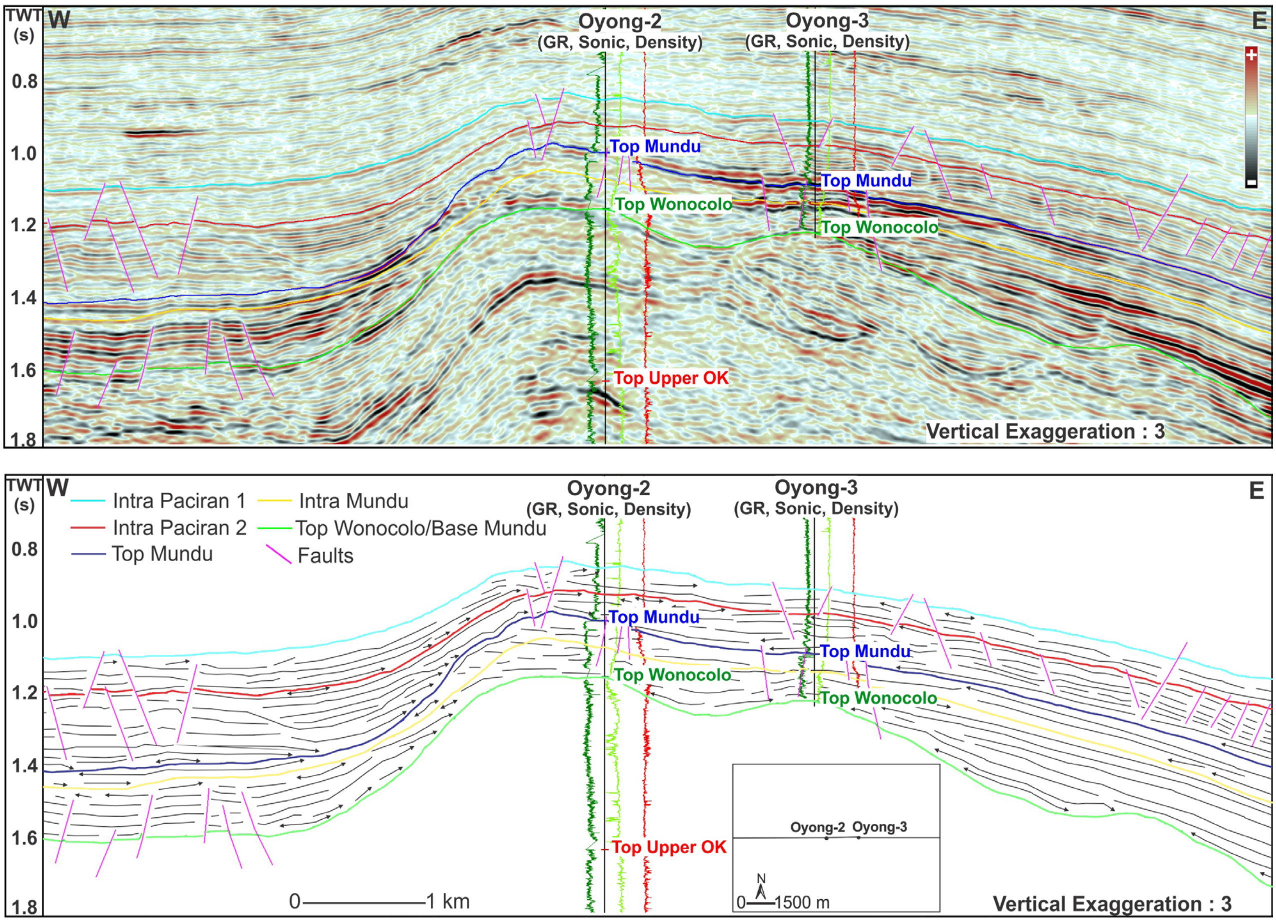

Figure 3. Arbitrary line crossing trough Oyong-2 and Oyong-3 shows reflection terminations in west-east direction

although there are some discontinued faults within Mundu Formation. They also do not extend into the upper unit above Intra Paciran 1 surface. Thus, based on the observations, two different times of faults formation had occurred in the studied interval. The first is after the Mundu Formation was deposited and the second occurred after the Intra Paciran 1 horizon was formed.

2.3. Colored Inversion Analysis

Colored inversion is the most objective seismic inversion method that can be applied as the study area does not have many well controls. The resulting acoustic impedance values from this method are heavily dependent on the interaction between the inversion operator with the seismic data itself rather than on the initial model.

Inversion analysis result for the wells is shown in Figure 4. In general, the synthetic correlation in all wells shows a good match, around 86 %. The inverted log values also follow the original log trends. In the crossplot of original acoustic impedance log versus the inverted acoustic impedance log, the correlation between these two values shows a good result, 0.89.

Moreover, it can be observed here that the frequency of the seismic traces in wells Oyong-1 and Oyong-2 is less than the frequency of the seismic trace in Oyong-3. This also is reflected in the inverted log and the synthetic result. The lower frequency traces in Oyong-1 and Oyong-2 are interpreted to be caused by the presence of thick gas column whereas, in Oyong-3, the reservoir is water filled. The lower frequency is due to the occurrence of gas column within the reservoir which absorbs the energy that passed through it.

Nevertheless, near the Top Mundu in Oyong-3 there is an anomaly in the circled area. The inverted log is deflected away and does not fit with the original acoustic impedance log curve. In comparison with Oyong-1 and Oyong-2, there is no anomaly at the Top Mundu. This is interpreted as the mismatch between the seismic and the well data.

2.4. Porosity Transformation

The result of the transformation is shown in Figure 5. The three best relationships between the porosity log and the AI inverted volume from the three wells is shown on the table in Figure 5A. The comparison of modeled porosity attribute with the 2 ms resampled porosity log also shows the decreasing trend of porosity value with depth in the wells (Figure 5B).

On the well section, the quality of the modeled porosity attribute in Oyong-1 and Oyong-2 is poorer than in Oyong-3. This is due to the input of the inversion volume at this area is influenced by the presence of gas column, as mentioned earlier. At the top of Mundu Formation in Oyong-3, the same error in the inversion analysis also exists.

3. Results and Discussion

3.1. Thickening and Thinning of the Mundu Formation

After mapping the horizons, the isochore maps were made to assess the thinning and thickening of the Mundu Formation. The Mundu Formation itself can be divided into two interval separated by the Intra Mundu horizon. To create the isochore map, these interval velocity values are used, 2073 m/s for Isochore 1 (upper interval) and 2500 m/s for Isochore 2 (lower interval). These interval velocities were derived from the well data.

The isochore between Intra Mundu and Base Mundu (Isochore 1) is generally thicker than the isochore between Top Mundu and Base Mundu (Isochore 2). The thickness difference between these intervals is almost threefold, 506 m thick of Isochore 1 compared to 169 m thick of Isochore 2 (Figure 6 and 7). Isochore 1 and 2 in the southern and southeastern area show a thicker unit (Figure 6 and 7). It can be observed that the Mundu Formation is characterized by sheet drape geometry. In the area where the thin interval is located, truncation and onlap on the

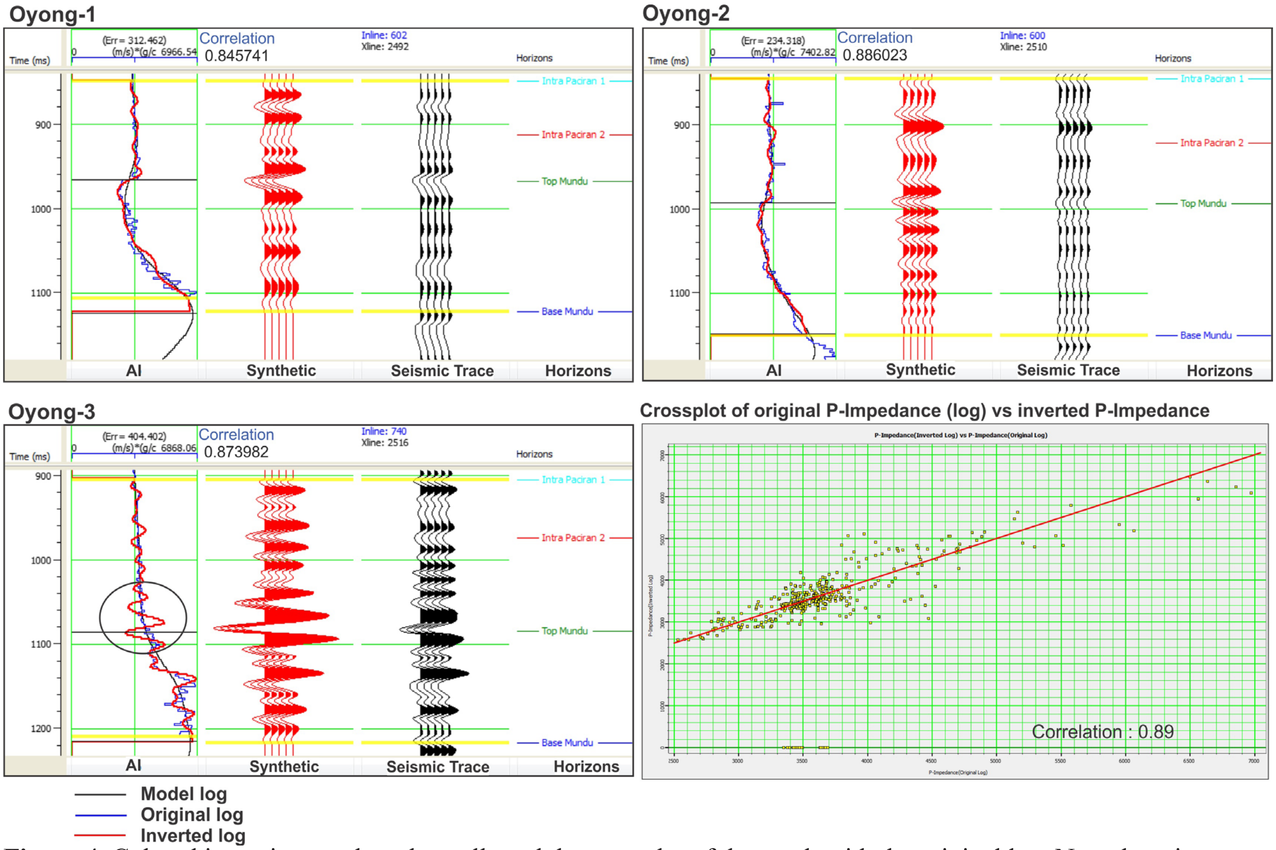

Figure 4. Colored inversion result at the wells and the crossplot of the result with the original log. Note there is anomaly near Top Mundu in Oyong-3.

A

Target	Attribute	Error	Correlation
1/Porosity	Inverted volume^2	0.044745	0.837229
1/Porosity	Inverted Volume	0.045328	0.826475
1/Porosity	Sqrt inverted volume	0.045956	0.817832

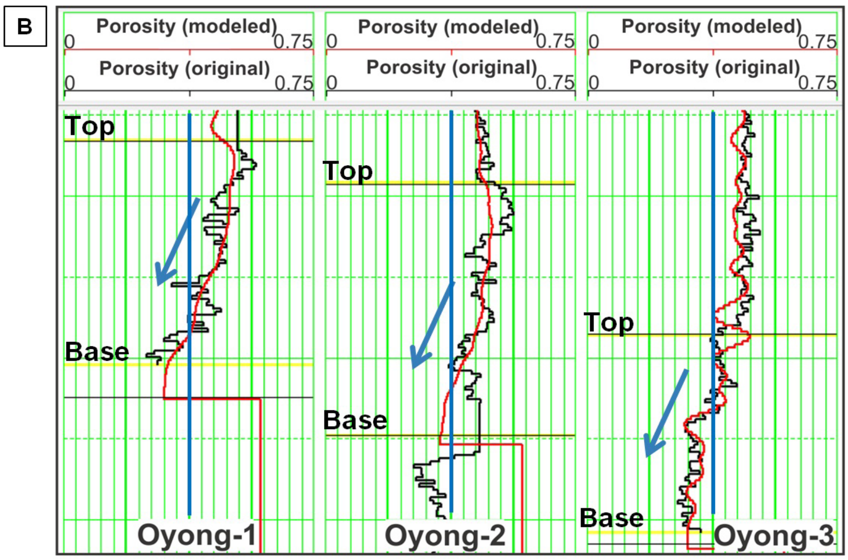

Figure 5. A) Table showing the three best statistical relationships between the porosity and acoustic impedance volume, B) The modeled new porosity attribute curve (red) compared to the original log (black), note that the porosity value is decreasing as the depth increases

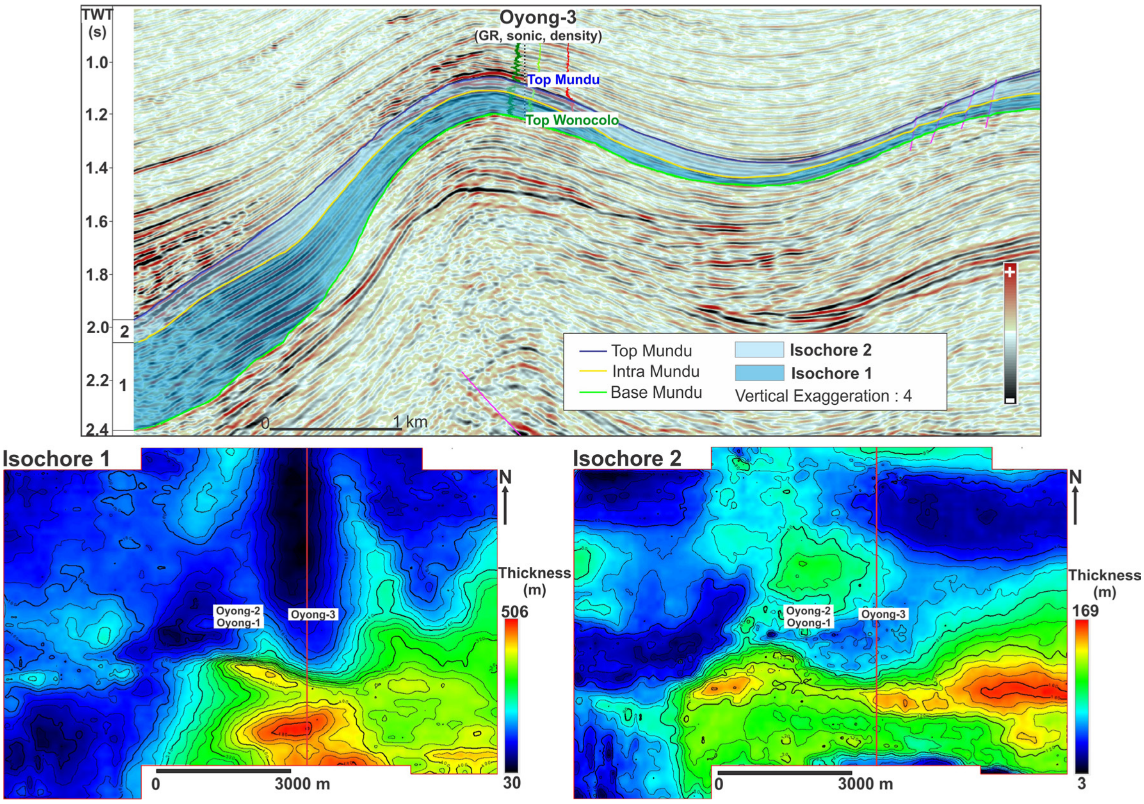

Figure 6. A north-south section through the area (upper figure) and two isochore maps (lower). Note the thickening of the reservoir towards the basinal area in the southern part.

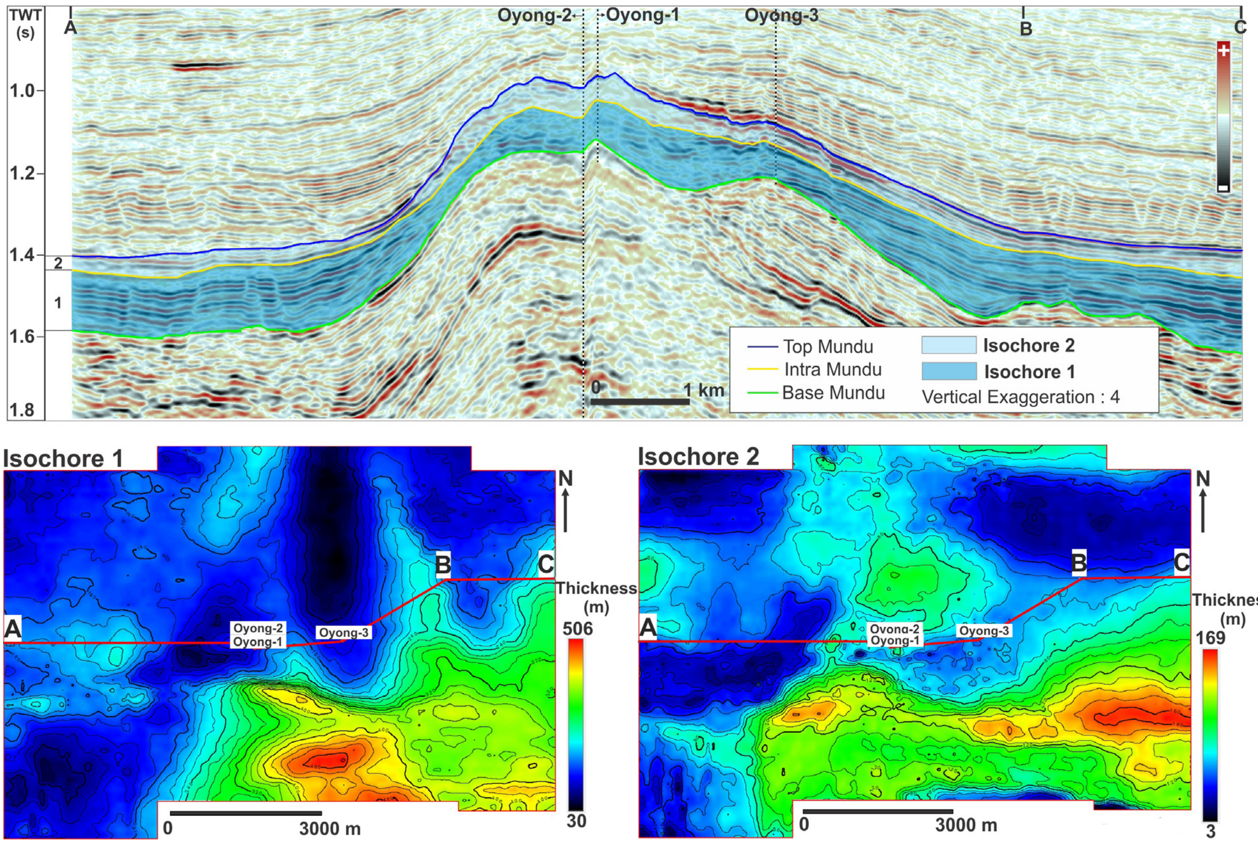

Figure 7. An east-west section through the area (upper figure) and two isochore maps (lower). Note the shape of the Base Mundu that influences the thickness of the reservoir and also note the relatively constant thickness of the isochore

horizons are mainly encountered. In the south-western area, both intervals are quite thin. There are onlapping reflectors from the eastern part onto this area and a truncation below Base Mundu horizon. The overall interpretation is that the southern and southeastern areas were positioned lower than the other areas resulting in more deposition. The truncation and onlap are evidence of an unconformity, indicating a sequence boundary. The deposition in the south-western area is thinner due to a pre-existing local high at the time of deposition.

3.2. Flatspot Identification

In the study area, there are two reflectors that its shape looks like a flatspot (Figure 8). In this line, the upper flatspot (upper black arrow) is quite horizontal while the lower flatspot is tilted (lower black arrow).

In the well section (Figure 9), the upper flatspot is interpreted to be located close to the gas oil contacts shown in the area around well Oyong-2 although the continuity of this flatspot is ambiguous.

The lower flatspot can be traced and coincides at the acoustic contrast around Oyong-3 (circled area). This lower flatspot in the Oyong-3 falls at a depth around 1000 m. From Top Mundu to 1000 m depth, the acoustic impedance log shows low value that represents oil trend for acoustic impedance.

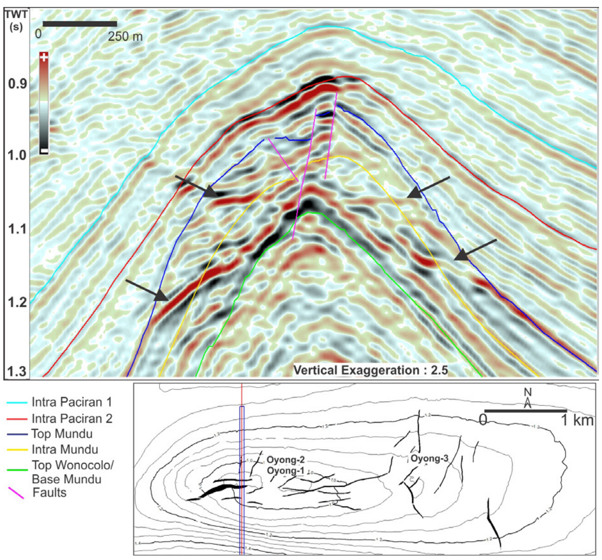

Figure 8. Two flatspots observed in the study area

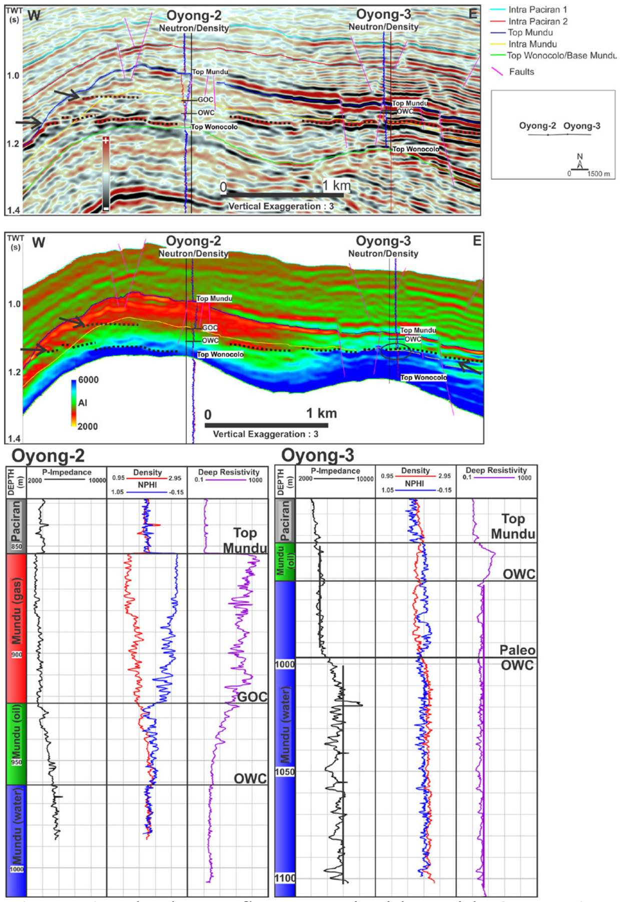

Figure 9. The lower flatspot coincides with Oyong-3 at depth around 1000 m which is interpreted as a paleo oil-water contact

On the other hand, the high resistivity value that represents oil only can be found from Top Mundu to 963 m. Meanwhile, from 963 m to 1000 m or until the Base Mundu shows low resistivity value that represents water.

In agreement with the seismic the crossover of neutron and density logs in yong-3 can be found until 1000 m depth. In the other wells, when the crossover of neutron-density log does not continue to the deeper part it represents the oil and water contact. Moreover, based on the pressure data of Oyong-3, the free-water level which is interpreted as oil water contact is located at depth 963 m. This oil water contact in Oyong-3 is located shallower than the intersecting depth between the lower flat spot and the well. Hence, at depth around 1000 m in Oyong-3, the lower flatspot is interpreted to coincide with the paleo oil water contact as there is disagreement between the acoustic impedance log and resistivity/neutron-density log.

3.2. Fracture Mapping

The similarity attribute is one of the coherence attribute, semblance based coherence, that principally measures the degree of similarity between the traces (Chopra and Marfurt, 2007). As faults are recognized by the discontinuities of the seismic traces, thus the degree of similarity of faults is low. An analysis window of 160 ms was input before creating the similarity volume which is considered large enough to accommodate fault discontinuities.

It can be seen on the surface of top reservoir (Top Mundu) in the area around the wells that the structural configuration forms an anticline which is associated with faults (Figure 10). Moreover, in the western part of the anticline, the occurrence of faults is higher compared to the eastern part. The intensity of the faults in the western part of the closure is shown by the heavily populated low similarity value which is thought to be a representative of the fractures. Thus, it can be concluded that the western area is a highly fractured area compared to the eastern area.

An analysis of the lineaments of the fractures on the top reservoir was also completed. On the rosette plot, the main fractures trend is relatively east-west (Figure 10). It is preferable to drill a deviated well perpendicular to the fractures trends to maximize the production on this closure.

It is interpreted that steeper closure on the western area and facies change influence the degree of fracturing on the closure. The steeper

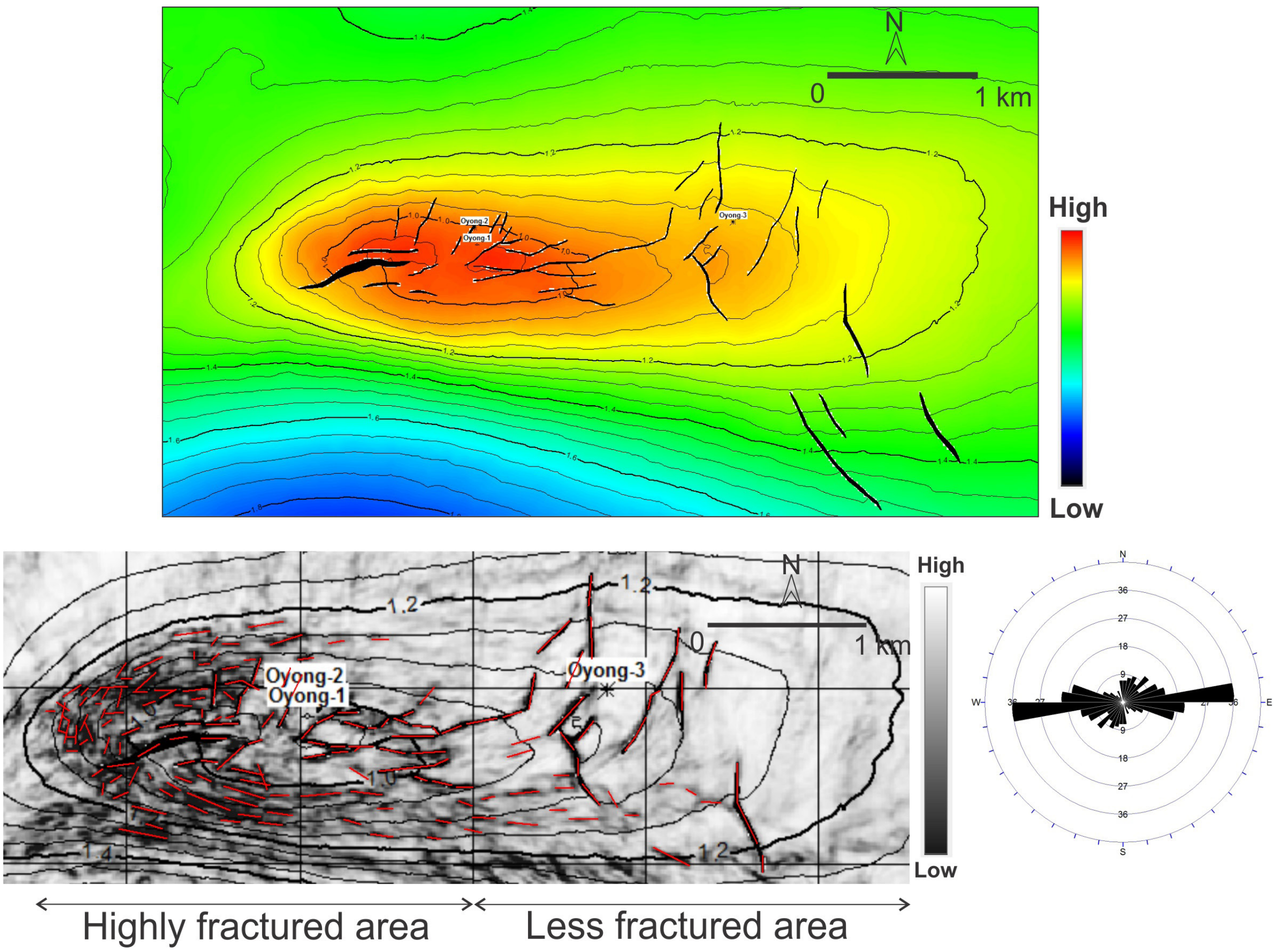

Figure 10. Time structural map of the top reservoir (above). The similarity attributes of the top reservoir overlain by the red lines that represents the interpretation of the fractures (bottom left). Rosette diagram of the fractures trend shows domination of east-west fractures (bottom right)

closure on the western area than the eastern area can enhance the formation of the fractures. Based on the core description in Oyong-2 and Oyong-3 (Tampubolon, 2016), it can be interpreted that the muddier facies on the eastern closure is more ductile than the sandier facies on the western closure.

3.4. Porosity Distribution

The result of the porosity transformation was applied to the seismic volume to determine the porosity distribution within the Mundu Formation. This porosity transformation from inversion volume does not reveal detailed changes of the porosity as observed in the porosity log curve but records general trends. Hence, this porosity volume records the change of the porosity trend across the wells (Figure 11). In general, the porosity trend in the seismic section shows that the area around Oyong-3 contains poorer porosity value (<40%) compared to the Oyong-1 and Oyong-2. The better porosity zone is included within the upper interval between Intra Mundu and Top Mundu (above yellow horizon). Thus, the upper interval contains better porosity compared to the lower interval. Moreover, the better porosity zone in Oyong-1 and Oyong-2 does not exist in the Oyong-3.

In the area between Oyong-2 and Oyong-3 (Figure 11), the blue colored and green colored porosity value appears to be inter fingering each other. Meanwhile, the top of the reservoir pick is analyzed as an unconformity surface with evidences of a time gap in biostratigraphy analysis, truncation and onlapping reflectors. The first observations leads to the interpretation of a facies change in between Oyong-2 and Oyong-3 that resulted in a lower porosity zone

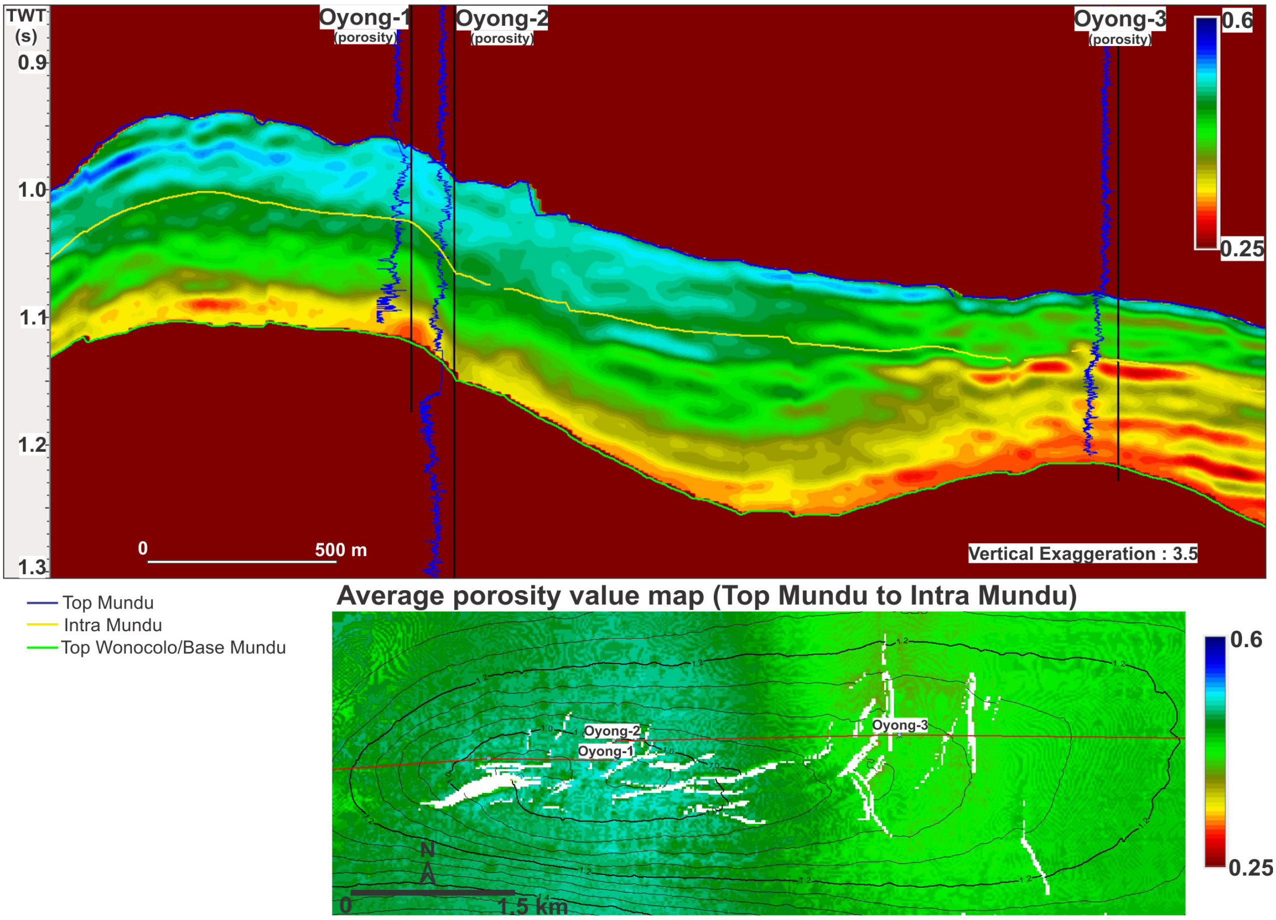

Figure 11. Porosity volume derived from the statistical relationship between porosity log and acoustic impedance (inverted volume). The better porosity zone does not exist in the area around Oyong-3. This can be caused by either the better reservoir was not developed in the Oyong-3 or had been eroded.

in the area of Oyong-3. Likewise, the characteristics of Top Mundu horizon as an unconformity surface also bring out the interpretation of possible erosion of the better porosity zone in Oyong-3. Therefore the higher porosity zone may have been present in Oyong-3 area but was eroded out. Thus, it is interpreted that the better porosity zone either did not develop in Oyong-3 due to facies change or it was already there but was later eroded out.

4. Conclusion

Within Mundu Formation, both intervals are thicker in the south and southeastern of the study area where the rest is relatively thin. Moreover, the upper interval is generally thicker than the lower depositional sequence. The thickening and thinning of the Mundu Formation is interpreted to be heavily influenced by paleotopography of its base.

The western part of the closure is considered as a highly fractured, whereas the eastern part of the closure is less fractured.

Around this closure, two flatspots are identified to be included within the Mundu Formation. The lower flatspot is related with the paleo oil water contact. The upper flatspot is related with a contact of gas either with oil or water.

Vertically, the more porous reservoir is located in the upper interval of Mundu Formation. Meanwhile, laterally, the area around Oyong-1 and Oyong-2 has better porosity than the area around Oyong-3.

It can be concluded that the best reservoir is located in the western closure of the anticline around Oyong-1 and Oyong-2. In this area, the area has better porosity, is highly fractured and filled by gas and oil

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