Mapping the Distribution and Characterization of Sandstone Reservoir Using Simultaneous Inversion Method in “OA” Field at Northern Bonaparte Basin

Oki Fimansyah Wiyatno¹, M. Syamsu Rosid¹*, and Humbang Purba²
¹Department of Physics, FMIPA Universitas Indonesia, Depok 16424, Indonesia
²Center for research and development of oil and gas technology "LEMIGAS", Cipulir 12230, Indonesia

* Email: syamsu.rosid@ui.ac.id

Abstract. The sandstone reservoir in the “OA” Field is situated in the Northern Bonaparte Basin, which is gas-saturated sandstone. Mineral diagenesis is also causing several reservoir zone areas to become tight sand. The inversion method using acoustic impedance (AI) is less sensitive in distinguishing sandstone and clay rock lithology since they have almost the same impedance. Simultaneous Inversion overcomes this problem by simultaneously inverting partial angle data (near, mid, far) to obtain physical parameters besides acoustic impedance which are expected to be more sensitive in distinguishing lithology and predicting the presence of gas fluids such as shear impedance (SI) and density. These three parameters can be derived as Lame (LMR) parameters. Cross plot analysis shows sensitive physical parameters to predict the distribution of lithology and the presence of gas fluid. Density sensitive in distinguishing lithology which is then inverted, obtaining sandstone cutoff values are 2.3-2.5 (g/cc), tight sand with cutoff 2.5-2.625 (g/cc) and clay stones with cutoff 2.625-2.8 (g/cc). The presence of gas fluid is predicted by inversing the parameter $V_p/V_s$ which has a cutoff of >1.6 and Lambda-rho cutoff of >25 (Gpa)*(g/cc). Analysis of the parameter distribution map shows the distribution of sandstones and the presence of dominant gas fluids in the northern area of the research zone with relatively clean sandstone, compared to relatively more southern regions.

1. Introduction

Reservoir characterization is an effort to describe the characteristics of rock physics and its fluid content by integrating geophysical data and petrophysical data. Reservoir characterization is done to find out the reservoir description qualitatively and quantitatively, generally using the Acoustic Impedance (AI) seismic inversion technique with P-wave impedance parameters. However, in its application this method is often encountered limitations in distinguishing lithological and fluid content effects. The field of the study area has a transition zone to shallow marine deposition zone, due to differences in deposition zones and rifting processes, separation of continents in the Middle Jurassic to Early Cretaceous along Australia's northwestern border, followed by collisions between the Indo-Australian and Sundanese plates from the Miocene until present days [1]. A tight sand zone was formed due to the insertion of shale and other minerals, so using AI parameters to characterize lithology alone would cause ambiguity.

In recent decades, people's interest in pre-stack inversion has increased because the inversion can be used to extract information about waves of compression and shear [2], [3]. One method that can be
used to do the inversion is simultaneous inversion. Simultaneous inversion is an inversion method using pre-stack CDP gather or partial stack as input to obtain not only acoustic impedance, but also shear impedance, and density [4]. By applying simultaneous inversion, it can be estimated that the shear impedance, $V_p/V_s$, has the same resolution as the acoustic impedance even though the property is mostly related to seismic far stack data with a low resolution. In addition, reliable estimation of density can also be derived from seismic data, which proves to be very useful for prediction of particular lithology and saturation [5].

So that the application of the simultaneous inversion method is expected to be effective to be used in characterizing and predicting the distribution of reservoirs in the "OA" Field of the Northern Bonaparte Basin which is estimated to have natural gas reservoirs in sandstone lithology.

2. Methodology

All of the methods that used in this study are to carried out the physical model of reservoir characterization and mapping of its distribution. The seismic data used is pre-stack seismic data in angle gather domain (0°-38°) with inline (2700-7372) and xline (3362-5682). Partial stack of seismic data are near stack seismic data (0°-8°), mid stack (8°-15°), and far stack (15°-38°). The seismic data has been preconditioned. Seismic data is controlled by 4 well data which shown in Table 1.

| Well Name | Gamma Ray | Density | P wave | S wave | NPHI | Caliper | SP |
|-----------|-----------|---------|--------|--------|------|---------|----|
| OA-1      | V         | V       | V      | V      | V    | V       | V  |
| OA-2      | V         | V       | V      | V      | V    | V       | V  |
| OA-3      | V         | V       | V      | V      | V    | V       | V  |
| OA-4      | V         | V       | V      | V      | V    | V       | V  |

2.1. Wavelet Extraction

The pre-stack seismic wavelet will depend on the incident angle, so it is necessary to do a wavelet extract for each partial stack. This wavelet will later become an important input in simultaneous inversion algorithms. Wavelet estimation is produced by the statistical extraction method in the study area which includes OA-1 to OA-4 wells as shown in Figure 1.

Figure 1. Wavelet extraction for each incident angle.
2.2. Pre-Inversion Analysis

Pre-inversion analysis is performed on well data and surrounding seismic data near the wells. This process done to conduct an inversion parameter interval experiment quickly and also as a benchmark for how successful this inversion result will become, along all the seismic data in the survey area.

The inversion parameter will reflect the relationship between \( \ln (Z_p) \), \( \ln (Z_s) \) and \( \ln (\text{Density}) \) obtained from the trend of linear regression lines illustrated in Figure 2. The cross plots \( \ln (Z_p) \) with \( \ln (Z_s) \) and \( \ln (Z_p) \) with \( \ln (\text{Density}) \) as a regression coefficient: \( k, k_c, m, m_c, \Delta L_s, \Delta L_d \) (highlighted in red box). This coefficient will be used in the inversion calculation process.

![Figure 2](image)

Figure 2. The curves show a linear trend of the regression line between \( \ln (Z_p) \), \( \ln (Z_s) \), \( \ln (\text{Density}) \) and the regression coefficient.

3. Results and Discussion

3.1. Sensitivity Analysis

The first step before carrying out the inversion process is to conduct a sensitivity analysis to see how sensitive the data we have in well log to identify the reservoir property. Well log data that usually used are gamma ray, density, neutron, acoustic impedance, and shear impedance. Figure 3 shows a crossplot between acoustic impedance and shear impedance with color scale of gamma ray of all well logs from OA-1 to OA-4. The crossplot is done to identify the lithology of reservoir. High gamma ray values indicating the lithology most likely to be shale, low gamma ray values indicating the lithology most likely to be sand. Unfortunately, those parameters aren’t too sensitive to separate lithology between sand and shale, this is due to an overlapping values both in acoustic impedance and shear impedance.
Figure 3. Crossplot of AI vs SI indicating that lithological separation that is not sensitive due to overlapping AI and SI values.

Other parameters then used to distinguish reservoir property which are more sensitive than acoustic impedance and shear impedance, that is by crossplotting $V_p/V_s$ vs density which shown in Figure 4. The crossplot is considered sensitive enough to distinguish clean sandstone lithology, shale and tight sandstone. The density parameter gives a cut off value for clean sandstone density 2.3-2.5 (g/cc), tight sandstone 2.5-2.625 (g/cc), shale 2.625-2.8 (g/cc). In general, the parameter $V_p/V_s$ is used to see the presence of hydrocarbons in the reservoir. The low $V_p/V_s$ ratio generally caused by the presence of hydrocarbons, gas especially. In this study, the low $V_p/V_s$ cutoff was in the value of $>1.6$ which is generally present in clean sandstone and tight sandstone lithology and the values are close to lithology of gas sand in, while the high $V_p/V_s$ has a cutoff $1.6<$ and generally in shale lithology [3].

Figure 4. Crossplot $V_p/V_s$ vs. density on wells OA-1 to OA-4 with gamma ray color scale, clean sandstone (yellow), shale (green), tight sandstone (orange).

In addition to the petrophysical parameters above, Goodway et al. published an approach that is a Lame parameter related to rigidity and incompressibility parameters [4]. These parameters can increase the level of identification of the reservoir zone because it is sensitive to changes in lithology and the presence of fluids. The Lame parameter is divided into two parameters, namely mu-rho ($\mu\rho$) and lambda-rho ($\lambda\rho$).

The parameter lambda-rho is a parameter that is highly related to rock incompressibility. The level of incompressibility of rocks is strongly influenced by the fluid that fills the pores of the rock because
the presence of fluid will affect how much mechanical interference is experienced in the rock when given normal directional pressure. That is why lambda-rho ($\lambda\rho$) is a very sensitive fluid indicator. The presence of gas in a rock will reduce the level of incompatibility due to the high level of compressibility of the gas so that the presence of gas in the sand will produce low lambda-rho.

The parameter of mu-rho is a parameter that is closely related to rock rigidity which is the level of rock resistance to attraction which results in a change in shape without changing the total volume of the rock [2]. Therefore, this parameter is not sensitive to the fluid contained in lithology but it is very good for distinguishing rock lithology. Crossplot between mu-rho and lambda-rho shown in Figure 5.

![Crossplot between mu-rho and lambda-rho](image)

**Figure 5.** Crossplot lambda-rho vs mu-rho in wells OA-1 to OA-4 with color scale of water saturation (top) and color scale of gamma ray (bottom).

It can be seen from Figure 5 that lambda-rho is quite sensitive in distinguishing the presence of hydrocarbon fluids. The sandstone reservoir is indicated by a low lambda-rho value at a value >25 (Gpa)*(g/cc) with low gamma ray and water saturation values. The cutoff value also approaches the lambda-rho cutoff value in Goodway et al. [3]. Mu-rho is less sensitive in distinguishing lithology of reservoir. It can be caused by diagenetic effects, due to high temperature and high pressure, causing rigidity between sand and shale lithology has almost have the same rigidity. Overburden pressure also
causes lithology to be more rigid. Besides, heavy mineral deposits such as siderite and pyrite cause lithological rigidity to be high.

3.2. Inversion Result
The target characterization and distribution of this study area is the Plover Formation which is deposited in the transition zone to the shallow sea. The Plover Formation is generally composed of quite dominant sandstones which intersect with claystone [6]. Density is a parameter that is quite sensitive to distinguish the lithology of the study area. The following results of slicing inversion density in the study zone can be seen in Figure 6. The density inversion results also show that the relatively well area in the south shows the dominance of the tight sandstone zone and several shale zones. This is supported by XRD data and petrography data that carried out by the lab analysis. The data was taken around the range of the reservoir zone in the relatively southern OA-3 wells among other wells. It shows that in the reservoir zone quartz overgrowth and siderite and pyrite minerals were deposited resulting tight reservoirs.

The emergence of siderite and pyrite minerals and quartz overgrowth is generally caused by diagenesis processes, chemical, physical, and biological processes that carry out sediment prior to the lithification process at certain temperatures [7]. Siderite and pyrite minerals are common to be found in the transition zone and coastal swamp environment [8]. Usually it occurs due to rocks containing rich carboniferous material (rich organic material) which is then altered due to diagenesis and is usually found in depositional areas which are relatively more landward in the transition zone.

Figure 6. The results of slicing the density section in the reservoir zone.

Fluid content in the reservoir is then estimated. Through crossplot of well data in the previous step, the parameters that are quite sensitive in distinguishing the presence of fluid in the reservoir are $V_p/V_s$ and lambda-rho. Slicing of $V_p/V_s$ shown in Figure 7 and slicing of lambda-rho shown in Figure 8.
Figure 7. Slicing of $V_p/V_s$ result at reservoir zone.

Figure 8. Result of lambda-rho slicing at reservoir zone.

The results of slicing the two parameters are not much different. The sandstone reservoir containing gas is indicated to have a low value of $V_p/V_s$ and lambda-rho. This is because the presence of gas will reduce the value of incompressibility in sandstones. The cutoff obtained refers to the crossplot of well data, lambda-rho at values >25 (Gpa)\((g/cc)\) and $V_p/V_s$ at a value of >1.6.
The results of slicing show that the presence of gas fluid is estimated to be more dominant in the relatively northern region of the “OA” Field. This can be happened due to the reservoir zone in a relatively more northern area having relatively clean sandstone. This is supported by the XRD data and petrography data on OA-2 well. The lab analysis shows that it has low level of quartz overgrowth, siderite, and pyrite accumulation. It resulting better porosity for gas fluids to be trapped, compared to relatively more southern regions. The XRD and petrography data on OA-3 well show that siderite, pyrite and quartz overgrowth accumulates more. This could be happened due to rocks containing rich carboniferous material (rich organic material) deposited more on the southern region which is then altered due to diagenesis process, thereby reducing the level of trapped gas fluid accumulation, due to the relatively smaller porosity.

4. Conclusion
Based on the results of the integrated interpretation of simultaneous inversion in the reservoir zone on Plover Formation, “OA” Field, Northern Bonaparte Basin, it can be concluded that simultaneous inversion parameters are good enough to characterize reservoir. Density is the most sensitive parameter to distinguish lithology, shale cutoff are 2.625 - 2.8 (g/cc), clean sandstone cutoff are 2.3 - 2.5 (g/cc), and tight sandstone cutoff are 2.5 - 2.625 (g/cc). $V_p/V_s$ and lambda-rho are sensitive to identify the presence of gas hydrocarbon, where $V_p/V_s$ cutoff are $>1.6$ and lambda-rho cutoff are $>25$ (Gpa)*(g/cc). Wells in relatively southern regions, namely OA-1 and OA-3 tend to be deposited more towards the land due to the discovery of quartz overgrowth, Pyrite and Siderite minerals which are more precipitated compared to relatively northern wells, OA-2 and OA-4. These minerals appear due to the diagenetic process and the presence of carboniferous material which tends to be found more in transitional areas that are closer to the land.

Acknowledgment
We would like to thank DRPM Universitas Indonesia for the beneficial financial support through PITTA grant no. NKB-0640/UN2.R3.1/HKP.05.00/2019

References
[1] Whittam D B, Norvick M S and McIntyre C L 1996 Mesozoic and Cainozoic tectonostratigraphy of Western ZOCA and Adjacent Areas. The APPEA Journal, 36, 209-231.
[2] Gray D and Andersen E 2000 Application of AVO and inversion to formation properties: World Oil, 221, July, 85–90.
[3] Goodway W, Chen T and Downton J 1997 Improved AVO fluid detection and lithology discrimination using Lame petrophysical parameters; “Lambda*Rho”, “Mu*Rho” and “Lambda/Mu fluid stack”, from P and S Inversions, CSEG meeting abstracts, 148–151.
[4] Hampson D P, Russell B H and Bankhead B 2005 Simultaneous inversion of pre-stack seismic data: 75th Annual International Meeting, SEG, Expanded Abstracts, 1633-1637.
[5] Maver, Kum G and Klaus B R 2004 Simultaneous AVO Inversion for Accurate Prediction of Rock Properties: Offshore Technology Conference abstract.
[6] Barber P, Carter P, Fraser T, Baillie P and Myers K 2003 Paleozoic and Mesozoic Petroleum System in The Timor and Arafura Seas, Eastern Indonesia, Proceedings Indonesia Petroleum Association 29th, Jakarta, Indonesia. IPA03-G-169.
[7] Hayes J B 1979 Sandstone diagenesis-whole truth. In Aspects of diagenesis (ds.P.A. Scholle and P.R. Schluger) SEPM Special Publication, 26, pp 127-140.
[8] Curtis C D and Coleman M L 1986 Controls on the precipitation of early diagenetic calcite, dolomite, and siderite concretions in complex depositional sequences, in Gautier, D.L., ed., Roles of Organic Matter in Sediment Diagenesis: SEPM, Special Publication 38, p. 23–33.