Integration of Post-stack Inversion and Rock Physics to Determine Sandstone Reservoir Quality: Barakan Sub-basin case

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Abstract. Barakan Sub-basin is assessed as potential basin for hydrocarbon reserves in the eastern region of Indonesia because it is adjacent to Masela block giant gas field. Reservoir rocks in this sub-basin are sandstones from Middle Jurassic (Lower Flamengo Formation) until Oligocene (Adi member Formation). Main sandstone reservoir rocks are knowingly studied to have good porosity in Upper Flamengo, Kopae, Ekmai and Adi member Formations. But, there is no significant study to determine sandstone reservoir distribution that have good porosity quality. Therefore, an integrated method of inversion and rock physics study are needed to determine sandstone reservoir quality. This study uses 2D marine seismic post-stack time migration and 2 wells namely Barakan-1 and Koba-1 wells. Sensitivity analysis with cross-plot of gamma ray log versus acoustic impedance values range of 20-60 API and 9000-42000 (ft/s)*(g/cc) shows a strong correlation of good porosity sandstone to low impedance in Ekmai Formation of both wells. Model based of post-stack inversion reveals sandstone distribution in Ekmai Formation of both wells. Time structure maps of top and bottom horizons in Ekmai Formation indicates Barakan-1 well within anticline height structure and Koba-1 well are deposited in a middle of sub-littoral environment.

Keywords: sandstone reservoir, rock physics, post-stack inversion, Ekmai Formation, Barakan Sub-basin

1. Introduction
Barakan Sub-basin is located on Western end of the Arafura Region and is part of the Northwestern Australian Continent. To the north and west it is bounded by the Aru Trench and Tanimbar Island, while to the east it is bounded by the Aru Islands. This basin is filled with series of Paleozoic, Mesozoic and Cenozoic sediments which are deposited inland into deep sea environment [1]. The direction that formed its structures are N-S and NE-SW, relatively. The N-S trending directional structures are formed during the Paleozoic due to tectonic extension occurring in this area. The tectonic event series are responsible to form Barakan Sub-basin. Furthermore, in the extension phase, sedimentary series filling occurs in the basin area and compression is occurred to lift the area. The last tectonic event is compression in the Late Tertiary associated with the subduction of plates in Banda arc. The tectonic above causes the erroneous of substances that have been formed to reactivate and become an upward and downward fault. The study area situated on Southwest Aru Waters in between 132°E – 135°E and 6°S – 9°S (Figure 1).
2. Data and Methodology

2.1. Well Data
Well log data and information such as marker formation, corrected check-shot of two wells, namely Barakan-1 and Koba-1 are acquired in this study. The types of well logging used are gamma ray, density neutron, resistivity and sonic logs.

2.2. Seismic Data
The seismic of total 85 2D post-stack seismic lines are acquired in this study. There are also 2 selected seismic lines, namely UT91KR and 83ARAFU which are nearest to Barakan-1 and Koba-1, and used for model based acoustic impedance inversion.

2.3. Petrophysical Analysis
Qualitative interpretation in this study uses gamma ray logs to identify permeable or impermeable zones due to the presence of natural radioactive elements which indicate rocks lithology. A quick look at the cross-over NPHI or Neutron Porosity Hydrogen Index curve against RHOB or bulk density curve which is overlaid each other with a range of opposite curves to indicate hydrocarbon reservoir [2]. Then, quantitative petrophysical analysis is applied to obtain the shale content of rocks, effective porosity, water saturation and permeability [3].

2.4. Acoustic Impedance
Acoustic Impedance (AI) is defined as the ability of rocks to pass seismic waves. The harder a rock is, the greater its acoustic impedance value [4]. Mathematically, acoustic impedance is a product of the multiplication of compression wave velocity and rock density, as described in following equation:

\[ AI = V \cdot \rho \text{ (ms}^{-1}\text{kgm}^{-3}) \]  \hspace{1cm} (1)

2.5. Seismic Inversion
Seismic inversion can be defined as a subsurface modeling technique using seismic data as input and well log data as control. This definition explains that the inversion method is the opposite forward modeling which is associated with making synthetic seismogram based on earth model. Based on the data source, the seismic inversion method into two groups, namely pre-stack inversion and post-stack inversion [5]. Inversion is a geophysical modeling that is carried out to predict information on the physical properties of the earth based on information obtained from seismic data.
3. Results and Discussion
Well correlation between Barakan-1 and Koba-1 shows significant differences where the two wells have complex formations in different vertical depths. Barakan-1 well has deeper and thicker formations than the Koba-1 well, so the target zones in both wells are fill in different depths (Figure 2). Identification of target zone aims to determine the lithology type of reservoir rock composition in the study area that has its own characteristics in the form of porous rocks and have good permeability. In this study, the reservoir rock is in sandstone lithology in both wells lies in Ekmai Formation at depth of 5360-6240 ft in Barakan-1 well and 3640-4200 ft in Koba-1 well.

In Barakan-1 well, reservoirs in Ekmai Formation are identified in two interval zones, at depths of 5630-5660 ft and 5990-6245 ft. These interval zones are limestone and sandstone lithology with gamma ray values range of 15.4-36.8 API. There are four interval zones identified as sandstone lithology in Ekmai Formation of Koba-1 well, at depths of 3703-3723 ft, 3877-3890 ft, 3933-3947 ft and 3957-4171 ft. Through quantitative calculations, these interval zones produce petrophysical parameters, namely shale volume ($V_{sh}$), effective porosity (PHIE), water saturation ($S_w$) and permeability ($k$) (Table 1).

![Figure 2. Barakan-1 and Koba-1 wells correlation](image)

| Formation | Well | Zone | Depth (ft) | Petrophysical parameters (Mean) | Litho |
|-----------|------|------|------------|---------------------------------|-------|
| Ekmai     | Barakan-1 | 1    | 5630-5660  | $V_{sh}$ 0.32, PHIE 0.04, $S_w$ 0.94, $k$ 0.03 | LS    |
|           |       | 2    | 5990-6245  | $V_{sh}$ 0.46, PHIE 0.15, $S_w$ 0.97, $k$ 1.9 | SS    |
|           | Koba-1 | 1    | 3703-3723  | $V_{sh}$ 0.34, PHIE 0.18, $S_w$ 0.95, $k$ 0.9 | SS    |
|           |       | 2    | 3877-3890  | $V_{sh}$ 0.45, PHIE 0.13, $S_w$ 0.99, $k$ 1.3 | SS    |
|           |       | 3    | 3933-3947  | $V_{sh}$ 0.33, PHIE 0.18, $S_w$ 0.99, $k$ 1.4 | SS    |
|           |       | 4    | 3957-4171  | $V_{sh}$ 0.34, PHIE 0.20, $S_w$ 1, $k$ 1.3 | SS    |

Shale volume in Ekmai Formation of both wells show a relatively small shale content which values range of 32-46%. These results signify the interval zones as reservoirs with less impurity content. Furthermore, shale volume will be accounted into water saturation ($S_w$) calculation. The porosity calculation in this study is performed to obtain effective porosity (PHIE) which is not influenced by the clay/shale content. These interval zones show fair to good porosity results except poor porosity (4%) in interval zone at depth of 5630-5660 ft. The classification of effective porosity value itself are based on ability to hold more hydrocarbon fluids [6]. High values of water saturation ($S_w$) are shown in all interval zones. It indicates that Ekmai Formation of both wells contain only small amount of hydrocarbon fluids.
and are dominated by water. These results also conclude that Ekmai Formation of Barakan-1 and Koba-1 are not qualified as hydrocarbon reservoir. Permeability values in these interval zones are less than 5 mD which are categorized as tight limestone and sandstone reservoirs.

Tuning thickness is influenced by the wavelength that passes through the rock, mathematically the value is $\lambda/4$ of the seismic wave that passes through the layer. In determining the value of tuning thickness, the average velocity ($V_p$) and dominant frequency of the target zone are needed [5]. The thickness of the target zone is greater than the thickness of the tuning, it causes the lack of accuracy of seismic cross section in the target zone (Table 2). This can be overcome by using acoustic impedance inversion that include low frequency information from the log data, whereas seismic data only has only a certain frequency ranges.

| Well       | $V_p$ average (m/s) | Dominant frequency (Hz) | $\lambda = V_p/f$ (m) | Tuning thickness $\lambda/4$ (m) | Target zone thickness (m) |
|------------|---------------------|-------------------------|-----------------------|----------------------------------|--------------------------|
| Barakan-1  | 3791                | 22                      | 172.32                | 43.08                            | 268.22                   |
| Koba-1     | 3207                | 21                      | 152.71                | 38.18                            | 170.69                   |

Pre-inversion analysis is done by comparing the curve value AI inversion, initial model and impedance in the quantitative calculation. The inversion method chosen in this analysis is model based which shows the best quantitative results from other two methods, namely bandlimited and sparse spike. Model based method show the correlation results of 0.991 with an error calculation of 0.136 in the Barakan-1 well and 0.992 with an error calculation of 0.127 in the Koba-1 well (Figure 3). The control parameters used in inversion analysis using this model based method are the constraints, the average block size, and the many iterations. High correlation and low error calculation results will increase the suitability of inversion model with the earth geological structures [7]. Based on the correlation and error values in the two wells, the results are good enough for inversion.

![Figure 3. Correlation results and error calculations of (a) Barakan-1 and (b) Koba-1 wells](image)

Model based of acoustic impedance inversion of Barakan-1 well in sandstone Ekmai Formation target zone shows that the acoustic impedance value range of 36,000-38,500 ((ft/s)²*(g/cc). The result of the AI inversion indicates the distribution of AI values spread across the target horizon which some exceptional areas of less representative the acoustic impedance (Figure 4). The result of the inversion of acoustic impedance values tend to be homogeneous and relatively high. It is suspected that the high content of clay materials at these depths can affect the sensitivity of the sonic log reading. High acoustic
impedance values can be caused by cementation process in the rock layers so that the rocks will become denser or more compact [8].

![Figure 4](image)

**Figure 4.** Ekmai Formation acoustic impedance inversion of Barakan-1 well

Model based of acoustic impedance inversion of Koba-1 well in sandstone Ekmai Formation target zone shows that the acoustic impedance value range of 9000-42000 (ft/s)*(g/cc), with green color indicates AI results at low values and purple color indicates high values. The distribution of low AI values are started at top horizon of Ekmai Formation and increased to high AI values to bottom horizon instantaneously. The inversion results show a match with the AI values in both wells which are indicated by similar color within formation from top to bottom horizons (Figure 5). The areas of formation with high AI values indicate denser sandstone reservoir, while areas with low AI values indicate more porous sandstone reservoir. That is because the AI values are the result of P-wave (Vp) and density that describes characters of the rocks within formation, where P-waves are propagating inside the matrix of the rock in its path, so that the denser the matrix of the rocks and smaller pores resulting in higher acoustic velocity. Whereas density values in the rocks are also influenced by the matrix density of them. So, the AI values are able to describe the character of the rocks properly and AI values are largely controlled by P-wave velocity values.

![Figure 5](image)

**Figure 5.** Ekmai Formation acoustic impedance inversion of Koba-1 well

Gridding method is applied in making top and bottom horizons of Ekmai Formation time structure maps to get the results of interpolated and extrapolated interval velocity values due to the limited amount of data. These two maps indicate the delineation of Ekmai Formation geological structures. On the basis of qualitative analysis, the location of Barakan-1 well within anticline height structure that is more towards the north of the well (Figure 6). The Ekmai Formation in Koba-1 well are comprised mainly sandstones with minor clays which were deposited in a middle sub-littoral environment.
4. Conclusion
Based on the results of the correlation between Barakan-1 and Koba-1 wells, there are complex geological formations and considerable depth differences. Well log data show lithology limestone and sandstone in Ekmai Formation. Petrophysical analysis conclude that Ekmai Formation of Barakan-1 and Koba-1 are not qualified as hydrocarbon reservoir. The AI values in the Ekmai Formation of Barakan-1 well are range of 36000-38500 ((ft/s) (g/cc) with the type of reservoir being sandstones, while in Koba-1 well Ekmai Formation is 9000–42000 (ft/s) (g/cc) which is sandstone as well. This result is in accordance with the cutoff value in the sensitivity analysis. Time structure maps describe no show of anticline structure as indication of hydrocarbon trap, so that Barakan-1 and Koba-1 are dry wells, but there is a possibility of height structure in the southeast of Barakan-1 well and northern of Koba-1 well.

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