Integrated analysis of inversion acoustic impedance method and spectral decomposition method for sandstone identification, case study Kutai Basin, Eastern Kalimantan

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Abstract. Seismic reflection is a method commonly used to map hydrocarbons. The reservoir can be characterized using the inversion method by converting the seismic data into acoustic impedance values of rock and spectral decomposition methods are used to delineate low-frequency shadow beneath reservoir caused by the presence of hydrocarbon. The combination of these two methods is used to distribute the hydrocarbon reservoir in the target zone. The inversion used in this research is a model-based inversion, while the spectral decomposition method used is continuous wavelet transform. The result of this study shows that reservoir distribution with low acoustic impedance located at inline 1583, inline 1290, inline 1360, inline 1399. Three of four inline show by spectral decomposition result delineating low-frequency shadow at inline 1290, inline 1360 dan inline 1399, while inline 1583 produces high-frequency anomaly. This phenomenon could occur due to the effect of reservoir thickness that is less than $\frac{1}{4}\lambda$. The reservoir has an acoustic impedance value of 18000–19000 ft.g/s.cc and low-frequency shadow beneath reservoir has 20 Hz frequency indicating the presence of hydrocarbon, while inline 1583 shows high-frequency anomaly 60 Hz this phenomenon shows that the reservoir thickness is thin or less than $\frac{1}{4}\lambda$ and indicates of containing gas fluid.

Keywords: Acoustic impedance inversion, Kutai Basin, high frequency anomaly, low frequency shadow, spectral decomposition

1. Introduction
Seismic reflection is a method commonly used to map the presence of hydrocarbon. The seismic reflection method is not only used for rock layering, but also can be used to map hydrocarbon traps. Furthermore, this information will be used further to delineate the presence of reservoir rock layers that contain hydrocarbons and map the hydrocarbon traps in the study area.

With advances in seismic processing and interpretation technology, reservoirs can be characterized using the inversion method and the spectral decomposition method. The purpose of the seismic inversion method is to find out the physical information of the reservoir rock such as porosity, density, fluid content directly from the seismic data. Also, this method can identify the distribution of the reservoir distribution in the target zone. The advantage of the spectral decomposition method is that it delineates low-frequency anomaly, which is related to the presence of hydrocarbon fluids, especially gases. Due to the nature of the fluid, especially gas, it absorbs the resulting frequency of seismic waves.
By combining the results from the inversion method and the spectral decomposition method, it will give optimal results in identifying the distribution of hydrocarbon reservoirs in the target zone.

The objectives of this study are to determine the acoustic impedance (AI) model for subsurface bedding using the acoustic impedance inversion method, to map the acoustic impedance values in the study area with the low acoustic impedance values as the main target, to identify the presence of reservoir rock layers that contain hydrocarbons at low frequencies using spectral decomposition, and identify the hydrocarbon zone through integrated interpretation and withdrawal based on the model parameters obtained.

Geographically, the observation field is part of the Kutai Basin, East Kalimantan, to be precise in the Lower Kutai Basin as shown in figure 1 [1]. The Kutai Basin is the deepest tertiary basin in Indonesia and has a sediment thickness of approximately 45,000 ft or about 13716 meters [2].

In the research area, the hydrocarbon source rock came from coal during the Miocene era and carbonaceous shale which was deposited in the fluvial delta-plain to delta-front environment [3]. According to Vo et al. [4], hydrocarbons in the observation field (DIM) are in sandstone reservoirs at the Middle Miocene interval and are related to the Balikpapan group. Sandstone in the Balikpapan group has a thickness of approximately 50–150 ft with an average of 80 ft [5]. The hydrocarbon traps in the Kutai Basin are closure type. The Kutai Basin has a common structural and stratigraphic trap. In the Kutai Basin, the Samarinda Anticlinorium structure is the main trap system that controls the formation of other traps. The cover rock in the Kutai Basin comes from the Balikpapan group and the Kampung Baru Formation, where the overburden is shale.

![Figure 1. DIM field research location in the Lower Kutai Basin, East Kalimantan.](image-url)
2. Methodology

This research method uses post-stack time migration (PSTM) seismic data and well data consisting of checkshot data, gamma ray log, sonic log, density log, porosity log, resistivity log, and water saturation log. In this research, the well data were first performed crossplot analysis to separate the hydrocarbon reservoir zones. Furthermore, seismic data and well data will be carried out well to seismic tie. After that acoustic impedance inversion is carried out so that the acoustic impedance value of subsurface rock layers is obtained. Next, the seismic data was analysed for the spectral decomposition attribute, so that the low-frequency anomaly was obtained. Inversion processing uses seismic data and well data as control data, while spectral decomposition processing only uses seismic data as input.

The results of acoustic impedance inversion and spectral decomposition will be interpreted and analysed for the distribution of hydrocarbon reservoirs. Also, the geological model is obtained from the results of integrating the two methods.

2.1. Seismic inversion

Seismic inversion is a technique for generating subsurface geological models with seismic data as the main data and well data for seismic data control [6]. In general, inversion seismic can be distinguished from input seismic data, namely post-stack seismic data and pre-stack or partial-stack seismic data. The results of seismic inversion are expected to obtain rock impedance values which are divided into two, namely acoustic impedance and elastic impedance, both of which contain information about rock parameters such as porosity, density, rock lithology, and other parameters. The acoustic impedance value generated from the post-stack inversion seismic will have information related to the rock layer.

2.2. Acoustic impedance

Acoustic impedance is a rock's ability to pass acoustic waves, where the acoustic impedance is obtained from the product of the value of the seismic wave velocity and the density of the rock itself. Changes in lithology, porosity, fluid content, temperature, and pressure at the subsurface are often associated with changes in acoustic impedance values. Therefore, to identify the presence of hydrocarbons, lithology, porosity, and so on can be seen with changes in acoustic impedance.

2.3. Spectral decomposition

Spectral decomposition is a geophysical method to facilitate the interpretation of seismic data. The spectral decomposition method has often been used in the world of oil and gas exploration to detect low-frequency shadows beneath hydrocarbon reservoirs [7]. Spectral decomposition is the process of decomposing the frequency spectrum of seismic data to simplify interpretation. Spectral decomposition has the main objective of characterizing subsurface rocks and reservoirs based on the frequency response [8]. In processing the data, Continuous Wavelet Transform (CWT) method used to produce a seismic section that has good resolution in the time-frequency domain. The underlying concept in the CWT method is to use the Fast Fourier Transform (FFT) method in each window continuously so that the results of the frequency range in the reservoir zone are obtained. The CWT method has a working principle of dilation and translation to produce a time-frequency scale map.

3. Results and discussion

3.1. Zone of interest

In Well_2_ADL (figure 2a) the thickness of the reservoir containing hydrocarbons is only 13 ft or less, while the rest is a reservoir containing water. As seen from figure 2a at a depth of 4895–4908 ft, the low Gamma Ray log values of 30–35 API indicate the reservoir lithology, and there is a cross over between the NPHI log and the Density log. With a high log resistivity value of 10–12 ohm-m and a low log of water saturation, it can be said that the reservoir contains hydrocarbon. At Well_1_DIM in figure 2b the reservoir thickness is approximately 365 ft, the low Gamma Ray log value of 25–38 API indicates
reservoir lithology, but it can be seen from figure 2b that the reservoir does not contain hydrocarbon because there is no crossover between the NPHI log and the density log. Also, resistivity log value at reservoir layer is low and water saturation log value is high, this indicates the reservoir layer at Well_1_DIM does not contain hydrocarbon.

3.2. Inversion acoustic impedance and spectral decomposition

The result of the inversion horizon overlay in figure 3a shows the spread of low (green-yellow) AI values. Low acoustic impedance values (18000 ft.g/s.cc) are associated with the reservoir zone, while in the structure closure (yellow arrow) the acoustic impedance values are not too low and have a range of colours around the red (20000 ft.g/s.cc) yellow (19000 ft.g/s.cc). The results of the spectral decomposition in figure 3b and figure 3c are overlaid with the time structure map. Anomaly at low frequency 20 Hz and high frequency 60 Hz have a similarity feature on low acoustic impedance anomaly shown by arrows. Based on the results 3 out of 4 research areas shown by arrows, the anomaly phenomenon of low-frequency shadow indicates the presence of hydrocarbon in the reservoir layer, while in 1583 (blue arrow) the resulting phenomenon is high-frequency anomaly.

![Figure 2](image-url)

**Figure 2.** (a) Zone of Interest Well_2_ADL, (b) Zone of Interest Well_1_DIM.

![Figure 3](image-url)

**Figure 3.** (a) Inversion acoustic impedance, (b) Spectral decomposition 20 Hz, and (c) Spectral decomposition 60 Hz.
Figure 3 (continued). (a) Inversion acoustic impedance, (b) Spectral decomposition 20 Hz, and (c) Spectral decomposition 60 Hz.

Figure 4a shows the results of the inversion (left) on inline 1290 showing that the layer has a low acoustic impedance value of 18000 ft.\(\text{g} / \text{s.cc}\) (green). This indicates that the layer is porous so that it fulfils the main requirements of a layer to become a reservoir. While the layer above it has a high impedance value of 24000 ft.\(\text{g} / \text{s.cc}\) (red) acoustic impedance, it can be said that the layer is a cap rock. In figure 4a the results of the spectral decomposition (right), at low frequency 20 Hz, the resulting magnitude spectrum is high (red colour) whereas high frequency 60 Hz not. This phenomenon can occur due to the nature of hydrocarbon, especially gas that attenuates high frequency. It is called low-frequency shadow indicates the presence of hydrocarbon. Inline 1360 figure 4b and inline 1390 figure 4c produce the same anomaly pattern as inline 1290. It is indicated by reservoir layer with low acoustic impedance values 18000 (green) – 20000 (yellow) ft.\(\text{g}/\text{s.cc}\). spectral decomposition results delineating that the layers with low acoustic impedance values have a high magnitude spectrum at low frequencies of 20 Hz, while in high frequency 60 Hz the presence of hydrocarbon attenuates the frequency so that the resulting magnitude spectrum is low.

In inversion acoustic impedance result (left) in figure 5. white circle indicates that the reservoir layer has a low AI value of around 18000–19000 ft.\(\text{g}/\text{s.cc}\), while the AI value for caprock is around 28000–30000 ft.\(\text{g}/\text{s.cc}\). The results of the spectral decomposition (right) in figure 5. shows that high magnitude (red colour) appears both in low frequency 20 Hz and high frequency 60 Hz. These phenomena occur because the effect of thin reservoir layer is equal to or less than \(\frac{1}{4} \lambda\) (one quarter of seismic wavelength). Based on the correlation between the well data at Well_2_ADL and the results of the inversion as well as the results of the spectral decomposition based on figure 4, and figure 5. It is proven that the thin layer reservoir contain hydrocarbon. Low frequency indicates that the layer contains hydrocarbon while high frequency indicates that the reservoir layer is thin. This phenomenon is called high-frequency anomaly.

3.3. Geological model

By integrating the two methods, it is known that the depositional environment in the DIM field research area is deltaic, with the direction of sediment supply from the Northwest to the Southeast indicated by the large yellow arrow. The traps in the study are, namely a combination of structural traps (closure) and stratigraphic traps. It is indicated by low acoustic impedance values and high magnitude spectra at low frequencies (20 Hz). The results of the geological model are shown in figure 6 [9].
Figure 4. Inversion acoustic impedance (left) and spectral decomposition (right) for 20 Hz (top) and 60 Hz (bottom) of (a) inline 1290, (b) inline 1360, and (c) inline 1399.
Figure 5. Inversion acoustic impedance (left), spectral decomposition (right) for 20 Hz (top) and 60 Hz (bottom) at inline 1583.

Figure 6. Spectral decomposition low frequency 20 Hz (top left), inversion acoustic impedance (top right) and geological model illustration of deltaic depositional environment (bottom).

4. Conclusion
Based on the results of the research that has been carried out, several conclusions can be drawn as follows: the results of the inversion using the model-based method can provide a good overview of the subsurface layers, with an acoustic impedance value of 18000–19000 ft.g/s.cc in the reservoir layer. Overlay of time structure map Top Reservoir results delineate the distribution of low acoustic impedance values in inline 1583, inline 1290, inline 1360 and inline 1399. The reservoir layer containing hydrocarbons has two different characteristics, namely the low-frequency shadow, this is indicated by
attenuation at high frequency, and high-frequency anomaly where high frequency and low frequency can have a high magnitude spectrum due to the effect of tuning thickness. The results of the distribution of low acoustic impedance values 18000–19000 ft/g.s/cc have a match with the distribution of spectral decomposition, where the reservoir layer indicates the presence of hydrocarbon.

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