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Telisa Formation Characterization Using Seismic Acoustic Impedance Inversion In The Akasia Area of The Central Sumatra Basin

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ABSTRACT - The Menggala, Bekasap, and Bangko formations are the main reservoirs in many productive oil fields in the Central Sumatra Basin. However, these three formations have been extensively explored and exploited, leading to high water saturation. Meanwhile, the Telisa Formation presents an opportunity for further exploration, as studies characterizing its gas reservoir in the Central Sumatra Basin remain relatively limited. This study aims to determine the characteristics of the Telisa Formation in the Akasia Area, Central Sumatra Basin, as part of a preliminary oil and gas exploration effort. The Telisa Formation in this area is a target zone for gas reservoir characterization studies. P-impedance parameters from acoustic impedance (AI) inversion analysis are used to identify rock lithology and fluid content. The AI inversion results indicate two lithology types shale and sandy shale confirmed through well data. High P-impedance values, ranging from 23,000 to 27,000 (ft/s)(g/cc), are identified as shale, while sandy shale exhibits lower P-impedance values, ranging from 12,500 to 22,000 (ft/s)(g/cc). Based on well-log analysis and seismic inversion, indications of hydrocarbons in the Telisa Formation of the Akasia Area are minimal or absent. The P-impedance transformation results show that the porosity distribution in the Telisa Formation is predominantly low, with slight variations in moderate porosity, ranging from 0.02 to 0.40 v/v, classifying it as poor to good porosity.

Keywords: reservoir characterization, acoustic impedance, central sumatra basin, telisa formation.

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INTRODUCTION

Oil demand in Indonesia continues to increase yearly, from 1,398 MBOPD in 2020 to 1,471 MBOPD in 2021 (BP 2022). However, oil production is decreasing because many wells are no longer producing (Setyono & Kiono 2021; Tamboesai 2017; Witasta et al. 2022). In 2021, oil production declined by 50,000 barrels per day compared to the previous year (BP 2022).

The Central Sumatra Basin has total natural gas reserves of 658.14 BSCF (Imron et al. 2021). The high gas reserves and the depletion of oil fields have led to a significant shift from oil production to gas production (Satyana et al. 2007). Therefore, exploration is needed to identify new gas sources.

Hydrocarbon accumulation in the Central Sumatra Basin is found in Early Miocene Sihapas Group sandstones, which originate from non-marine Oligocene Pematang host rocks (Satyana et al. 2007). These sandstones comprise the Menggala, Bangko, Bekasap, Telisa, and Duri Formations. The Menggala, Bekasap, and Bangko Formations are recognized as the main reservoirs of many productive oil fields in the Central Sumatra Basin (Diria et al. 2018).

In this study, the Akasia Area's Telisa Formation, is the primary target for gas exploration. The formation is characterized by low porosity and permeability. It is, therefore, underdeveloped and is better known as a cap rock layer that effectively restricts the movement of hydrocarbons in the subsurface (Marpaung et al. 2010). Although the Menggala, Bekasap, and Bangko Formations are recognized as major reservoirs, not all parts of these formations exhibit the expected reservoir properties. For example, the Menggala Formation has a water saturation of 50.3%-57.3% with a reservoir thickness of 8-27 meters (Pratama et al. 2018). The Bekasap Formation has a water saturation of 55%-89% and a reservoir thickness of 3-13 meters (Anugrah 2015), while the Bangko Formation has a water saturation of 24%-46% with a reservoir thickness of only 5-7 meters (Adinur et al. 2019).

The high water saturation in the three formations indicates that the reservoir zone will primarily produce formation water, while hydrocarbons tend to remain trapped in the reservoir (Widarsono 2008). Additionally, the relatively thin reservoir layer, which serves as a site for hydrocarbon accumulation, results in less favorable prospects for further exploration. Meanwhile, the sandstones of the Telisa Formation have water saturation values ranging from 30% to 40% and porosity between 10% and 20%, which can be categorized as fair to good (Koesoemadinata 1980). The volumetric hydrocarbon estimate reaches 36,723 MSTB (Diria et al. 2018), with a heterogeneous depth of approximately 167 meters below sea level and a thickness of 30-45 meters (Putra et al. 2022). Although the Telisa Formation is generally recognized as a cap rock, it has been proven to function as a reservoir in several fields where hydrocarbons are being developed and produced, such as in Bintang Field (Nukefi 2021), Beruk Field (Diria et al. 2018), Rokan Block (Susianto et al. 2023), and BLSO Field (Putra et al. 2022). This demonstrates that the Telisa Formation, in addition to acting as a cap rock, also has the potential to serve as a hydrocarbon reservoir in isolated sandstone layers within low-permeability shales (Diria et al. 2018).

In the Akasia Area, no studies have characterized reservoirs in the Telisa Formation. This formation could serve as a new alternative gas resource to the Menggala, Bekasap, and Bangko Formations. Thus, the Telisa Formation in the Akasia Area is a prime target for gas exploration.

Studies on the hydrocarbon potential of the Telisa Formation have been conducted by Nukefi (2021); Diria et al. (2018), however, their seismic results did not identify fluid content in the reservoir. In addition, (Susianto et al. 2023) conducted a similar study that focused solely on the geological perspective of well data and did not map the fluid content and distribution of the reservoir.

The Telisa Formation in Bintang Field, Beruk Field, and Rokan Block has been shown to contain hydrocarbons (Diria et al. 2018; Nukefi 2021; Susianto et al. 2023), with Telisa sand in BLSO Field being an oil-producing reservoir (Putra et al. 2022). However, Central Sumatra undergoes complex deformation, including folds, faults, and compression-decompression zones, which impact the distribution of host rocks and geological structures (Kausarian et al. 2023; Marpaung et al. 2010).

Therefore, it is necessary to explore whether the Telisa Formation in the Akasia Area has the potential to serve as a hydrocarbon reservoir, as observed in other locations. This study provides a basis for further exploration of the Telisa Formation for gas in the Akasia Area.

Reservoir characterization is essential and should be performed using seismic inversion methods that formulate subsurface models (Triyoso et al. 2024) by integrating seismic data and well logs as controls. Acoustic impedance (AI) inversion has been successfully used for reservoir characterization and hydrocarbon prospect identification in the Central Sumatra Basin (Aisyah et al. 2024; Butar et al. 2023; Suwondo et al. 2019). To enhance the accuracy of AI interpretation results, seismic attributes should be added as additional constraints. The sweetness attribute is used to identify sweet spots that may contain hydrocarbons, where high sweetness values in seismic data can indicate the presence of hydrocarbons (Aviani et al. 2022; Emujakporue & Enyenihi 2020; Pamalik et al. 2020). Combining the AI seismic inversion method and the sweetness attribute will provide comprehensive information for characterizing hydrocarbon reservoirs. The results of this study will offer further insights into the lithology and fluid content in the Akasia Area.

METHODOLOGY

This study uses 2D seismic post-stack time migration data, supported by data from four well logs, which were applied in this study. The seismic and well-log data are presented in Table 1 and Table 2.

Table 1. Seismic data

Seismic Data	Sample Rate (ms)
Line 1	2
Line 2	2
Line 3	2
Line 4	4

Table 2. Log data from four wells

Log Data	R-1	R-2	R-3	R-4
GR	√	√	√	√
Caliper	√	√	√	√
NPHI	-	-	√	√
CNL	√	√	-	√
RHOB	√	√	√	√
Resistivity	√	√	-	√

Acoustic impedance

AI results from multiplying the density and the velocity of primary waves (*Vp*). Primary waves are longitudinal compression waves influenced by rock content and structures, such as porosity, matrix compressibility, fluid compressibility, and density (Veeken 2007), making them useful for hydrocarbon indication. This AI value represents the AI when the wave arrives at an angle of 0°. AI can be formulated as follows:

$$AI = \rho . V_{p}, \quad (1)$$

where ρ is rock density and V_p is the P-wave velocity.

Gardner et al. (1974) determined an empirical equation describing the relationship between the velocity of seismic P-waves and the bulk density of lithology:

$$\rho = aV^{b}, \quad (2)$$

where ρ is measured in g/cm³, is 0.23 when is in ft/s, and is 0.25.

AI is analogous to acoustic hardness (Sukmono, 2000). Hard and incompressible rocks, such as limestone, have high AI, whereas soft rocks, such as clay, are easily compressible and have low AI.

Model-based inversion

Model-based inversion (MBI) is a post-stack inversion technique used to calculate the AI of seismic data sets. This method is based on convolutional theory, which describes a seismic trace as the convolution result of a wavelet and a reflectivity function. However, the seismic trace is degraded by noise, as multiple factors both instrumental and cultural noise affect the data as described in Equation 3..

$$\textit{Seismic trace} = \textit{Wavelet} * \textit{Reflectivity} + \textit{Noise}. \quad (3)$$

Unless the noise in the data is related to the seismic signal, it can be solved for the rock reflectivity function. The following nonlinear equation is an iterative AI solver (Latimer et al. 2000):

$$r_i = (Z_{i+1} - Z_i)/(Z_{i+1} + Z_i) \quad (4)$$

$$AI_N = AI_1 \exp\left(2\sum_{i=2}^{N} r_i\right). \quad (5)$$

In practice, the equation is applied in recursive inversion to convert the reflectivity function into AI, which is the final objective. represents the AI of the first (top) layer, while is the AI of the *N-th* layer and is the reflection coefficient of the *i-th* layer

, r_i is the reflection coefficient of the i-th layer, Z is the acoustic impedance, and Z_i is the acoustic impedance of the i-th layer..

The study was conducted in several steps, beginning with data preparation, including post-stack seismic data, well data, and regional geology. The first step was to analyze the well data to identify lithology type and fluid content, followed by a cross-plot analysis of the well data. Next, wavelets from the post-stack seismic data were extracted, and seismic and well data were tied using the well-to-seismic tie process. Marker selection was performed based on the horizon contained in the well data. The sweetness attribute was then applied to search for gas indications.

An initial model for AI was created, and AI inversion was performed using a model-based approach. Porosity cross-sections were then generated by establishing a linear relationship between AI and porosity. Finally, lithology and reservoir fluid content were identified using the parameters obtained from AI inversion results.

RESULT AND DISCUSSION

Well data analysis

Well-log data is subsurface data that is sensitive to changes in rock layers, making it useful for identifying reservoir target zones. Target zone identification is performed by analyzing quick-look interpretations of log data responses in the form of single curves. The results of the log data analysis for the R-1, R-2, R-3, and R-4 wells in the Telisa Formation are shown in Figures 1 to 4, marked with black boxes.

The Telisa Formation in the Akasia Area is a target reservoir zone. The analysis was conducted on the reservoir zone between the top horizon of SB-3 Telisa and the top horizon of SB-2 Lakat. This analysis was applied to identify reservoir lithology and fluid content. In the R-1 well, the area of interest is located at a depth of 640–1,158 meters, where two types of lithology were identified: sandy shale and shale.

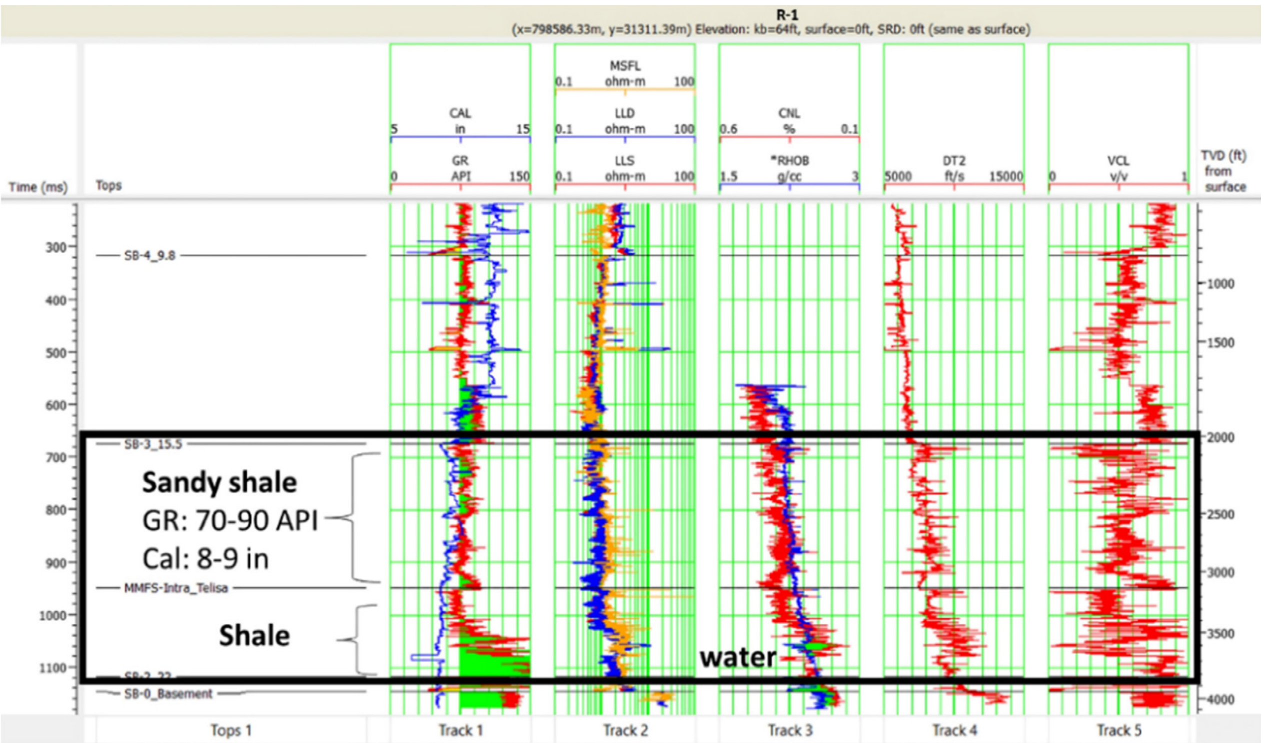

Figure 1. Log data of the R-1 well in the telisa formation of the Akasia area.

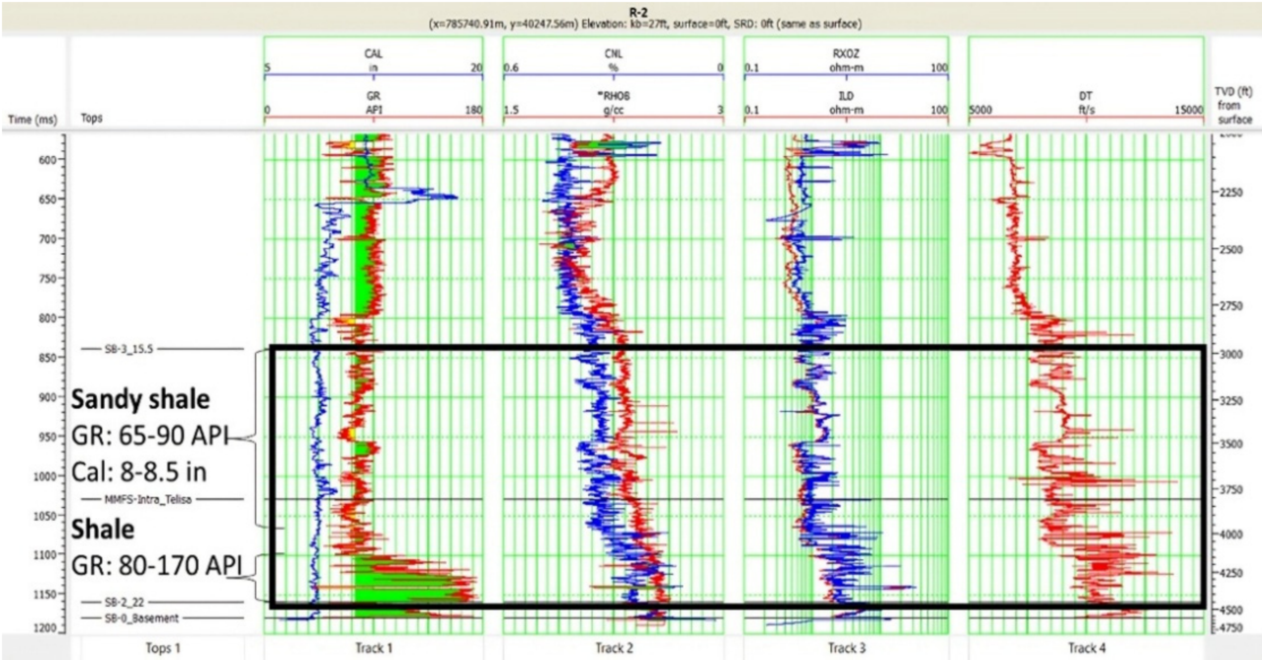

Figure 2. Log data of the R-2 well in the telisa formation of the Akasia area.

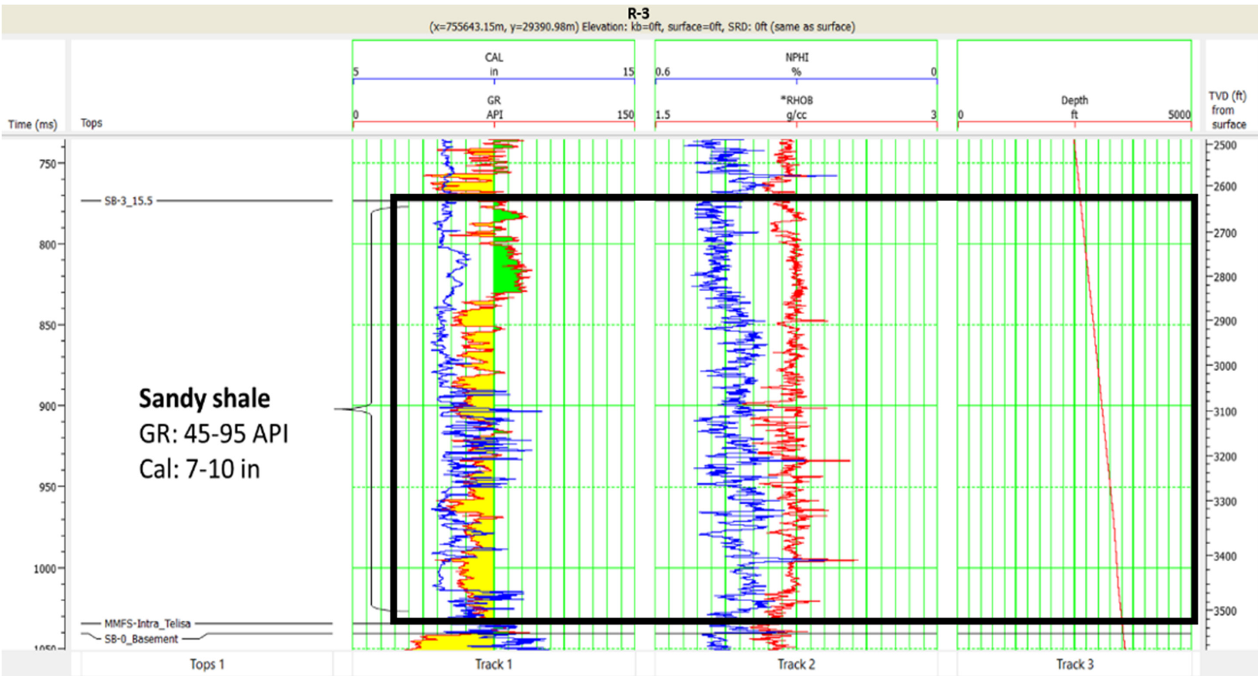

Figure 3. Log data of the R-3 well in the telisa formation of the Akasia area.

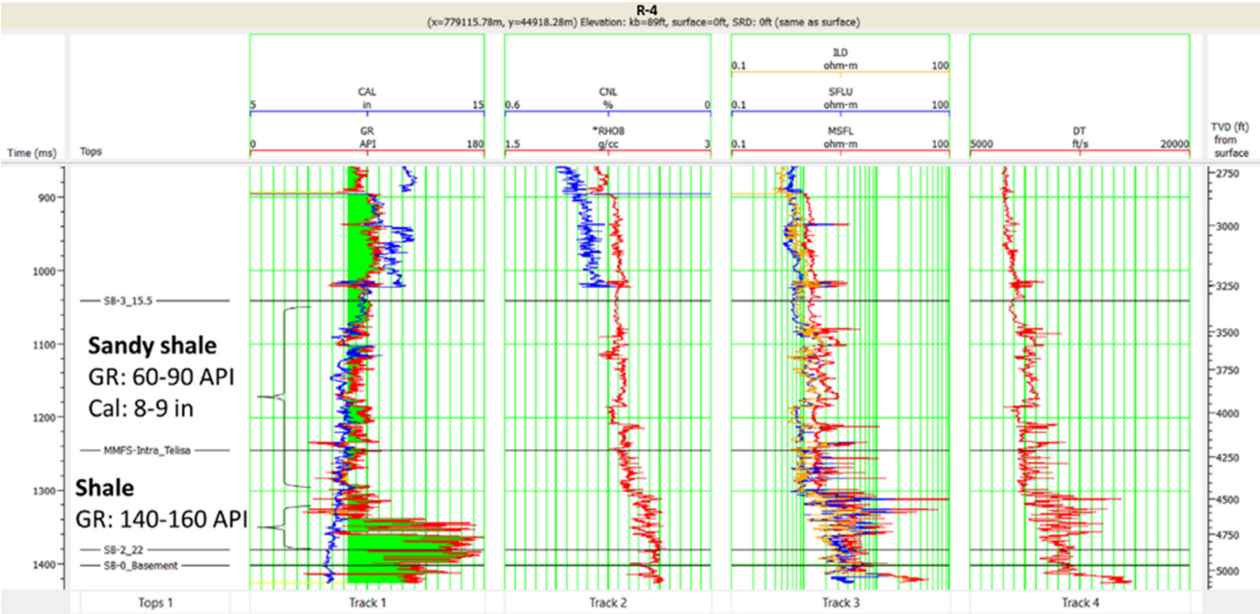

Figure 4. Log data of the R-4 well in the telisa formation of the Akasia area.

The target zone contains water reservoirs, which can be identified through the characteristics of log curves. The lithology type of the reservoir is identified using the log caliper and log gamma ray (GR) simultaneously on Track 1. The GR log distinguishes whether the lithology is shale or non-shale. This method measures gamma radiation from radioactive elements in rock layers along the borehole, which are generally more abundant in shale.

In the R-1 well, the GR log curve at depths of 1,036–1,127 meters shows an increase in value up to 150 API, indicating shale lithology at that depth. As the depth increases, the caliper log value decreases, suggesting the possible presence of shale rock. Water-saturated shale layers expand and narrow the borehole diameter.

Based on the analysis of the three resistivity logs (MSFL, LLS, and LLD) in Track 2, there is no deflection in the curves for either the invaded zone (MSFL and LLS) or the uninvaded zone (LLD). This suggests that the lithology is likely impermeable. In addition, the low resistivity value (around 10 ohm-m) is thought to result from water content in shale binding the rock, as water has high conductivity (Anindita 2023). This indicates the absence of hydrocarbons and suggests that the formation contains only water fluid. If a reservoir contains hydrocarbons, the log resistivity value is usually high, reaching around 100 ohm-m, due to the highly resistive nature of hydrocarbons (Mulyatno et al. 2018).

Next, the neutron and density logs in Track 3 were combined to analyze the crossover pattern, where both are inversely proportional if hydrocarbons are present. The presence of hydrocarbons causes a decrease in neutron and density values. This is due to the collision principle between neutron particles and hydrogen atoms. The energy from neutrons passing through rock formations is absorbed when colliding with hydrogen atoms. Therefore, the number of detected neutrons is inversely proportional to the amount of hydrogen atoms in the formation. This hydrogen content is proportional to the pore volume that hydrocarbons can fill.

Meanwhile, log density is based on energy absorption from photons emitted by radioactive material. As photons travel from the emitter, some collide with electrons in the formation, releasing energy and scattering. The number of photons is directly related to the number of electrons in the formation and is converted into an equivalent rock density value. The more photons returned, the less ability the formation has to absorb them, indicating low density (Schlumberger 2016).

The larger the crossover separation indicated by the neutron and density logs, the more likely it is to be interpreted as gaseous hydrocarbons. If the separation is slightly smaller, it can be interpreted as oil or water.

In the R-1 well, the small crossover suggests that the reservoir contains water (Schlumberger 2016).

The sonic log shows an increase in value with depth, indicating that the lithology becomes tighter and the seismic wave velocity increases. Furthermore, in Track 5, the VCL (volume clay) log shows a curve with a large value, suggesting that the Telisa Formation in R-1 is dominated by clay. Based on the analysis of several logs, it can be determined that the Telisa Formation contains sandy shale and shale lithologies, with the fluid being water and no hydrocarbons detected.

The zones of interest in the other three wells R-2, R-3, and R-4 have the same lithology as the R-1 well, namely sandy shale and shale, based on the gamma-ray log curve characteristics. However, no fluid was found in the R-2 and R-3 wells due to the lack of crossover in the neutron and density logs. In the R-4 well, the fluid content could not be further identified due to the absence of neutron log data for crossover analysis.

Sensitivity analysis

Sensitivity analysis is performed to identify sensitive parameters in determining lithology and fluid content in well data. The fluid content in rock pores can be determined using the P-impedance cross-plot. The P-impedance value is influenced by rock density, P-wave velocity, and fluid content in rock pores. The rock incompressibility parameter (λ) in P-wave velocity also affects the P-impedance value, which varies according to the fluid type. Gas has the lowest incompressibility value compared to oil and water, resulting in a lower P-wave velocity when passing through gaseous fluids (Rosid et al. 2019a).

At this stage, a cross-plot between two parameters from well data in the reservoir area (Telisa Formation) was performed, specifically a cross-plot between AI and Density (RHOB) to obtain lithological characteristics in the reservoir zone, with GR color bars, as shown in Figure 5.

The sandy shale zone is marked in green, while the shale zone is purple. In the cross-plot, the lithological separation is still not well-defined, as shown by the different density values, even though the AI values are the same (overlap). Density values around 2.15–2.45 g/cc are identified as sandy shale, while shale has density values in the range of 2.45–2.65 g/cc. This is because the AI value reflects both the type of lithology and the fluid content within it (Rosid et al. 2019a).

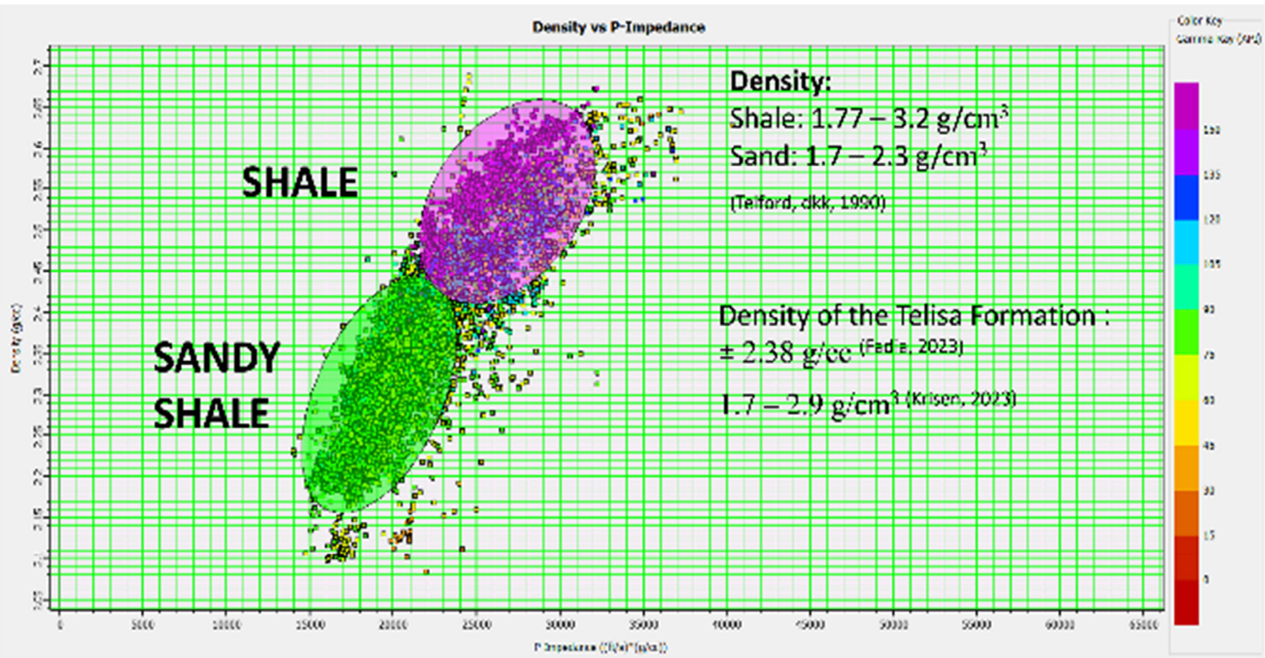

Figure 5. Cross-plot of density and P-impedance with color bar of gamma ray values.

Depth structure map

The structure in the depth domain of the study area is depicted in the depth structure map shown in Figure 6. In the figure, the northern area, depicted in orange-red, represents the highest elevation, while the southeastern area, shown in purple-blue, is lower in elevation. Tectonic uplift during the Plio-Pleistocene phase has formed shallow reservoirs in the west and northeast of the Central Sumatra Basin (Yensusnimar 2021). The four wells, marked with red stars, are located in the fault zone. They are positioned in areas with tight contours, which may allow hydrocarbons to migrate to shallower layers, leaving behind only water, as observed in the R-1 well in Figure 1.

Sweetness attribute

The sweetness attribute, derived from amplitude and frequency, is used to identify "sweet spot" anomalies that may indicate the presence of hydrocarbons (Zulivandama et al. 2018). Before interpretation, these anomalies must be matched with well data. Figure 7 presents the output of the sweetness attribute.

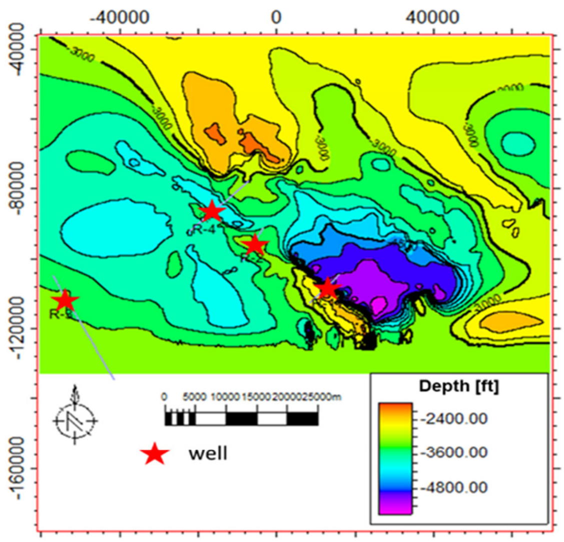

Figure 6. Depth structure map of the telisa formation in the Akasia area.

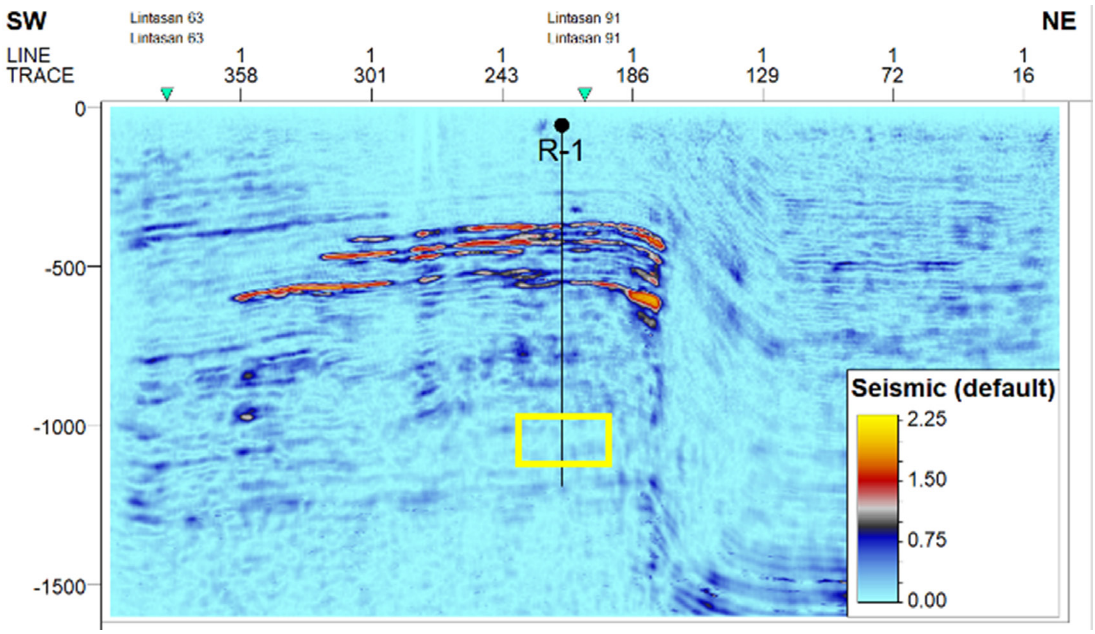

Figure 7. Sweetness attribute on the seismic cross-section of the R-1 well.

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Based on the neutron and density log crossover in the Telisa Formation of the R-1 well, within the time range of 1,000–1,100 ms, the sweetness analysis focuses on the yellow box between traces 186–243, which is near the R-1 well. The yellow color indicates high sweetness values, whereas the cyan color represents low values. A low sweetness value characterizes an area with low amplitude and high-frequency values.

The appearance of a sweet spot may result from a velocity contrast between a high-velocity rock layer and a low-velocity material (presumably hydrocarbons). However, in the yellow box in Figure 7, the sweetness value is relatively low and does not indicate a sweet spot anomaly, suggesting the absence of velocity contrast and hydrocarbons in the zone.

Acoustic impedance inversion

The seismic inversion indicates the distribution of lateral AI values in the reservoir target zone. P-impedance is influenced by primary wave velocity (V_p) and density (ρ). Figure 8 shows the inversion model of the telisa formation in the 700–1,100 ms range.

Based on the cross-plot data, there is some overlap in separating shale lithology from other lithologies. High P-impedance values, indicated by cyan to blue colors (23,000–27,000 [ft/s][g/cc]), are associated with shale lithologies, while sandy shale is identified by lower values (12,500–22,000 [ft/s][g/cc]), represented in green to brownish-red colors.

In the target zone, there is a slight P-impedance anomaly, indicating a small incompressibility value that could suggest the presence of hydrocarbon gas (Rosid et al. 2019b).

However, the R-1 well data did not verify the presence of gas but rather water fluid. This suggests that the low P-impedance value is more influenced by the rigidity parameter (μ) than the incompressibility (λ) at the primary wave velocity (V_p). The rigidity parameter is verified by the presence of sandy shale lithology in the well data. Sandy shale lithology leads to low rock density and, consequently, low P-impedance.

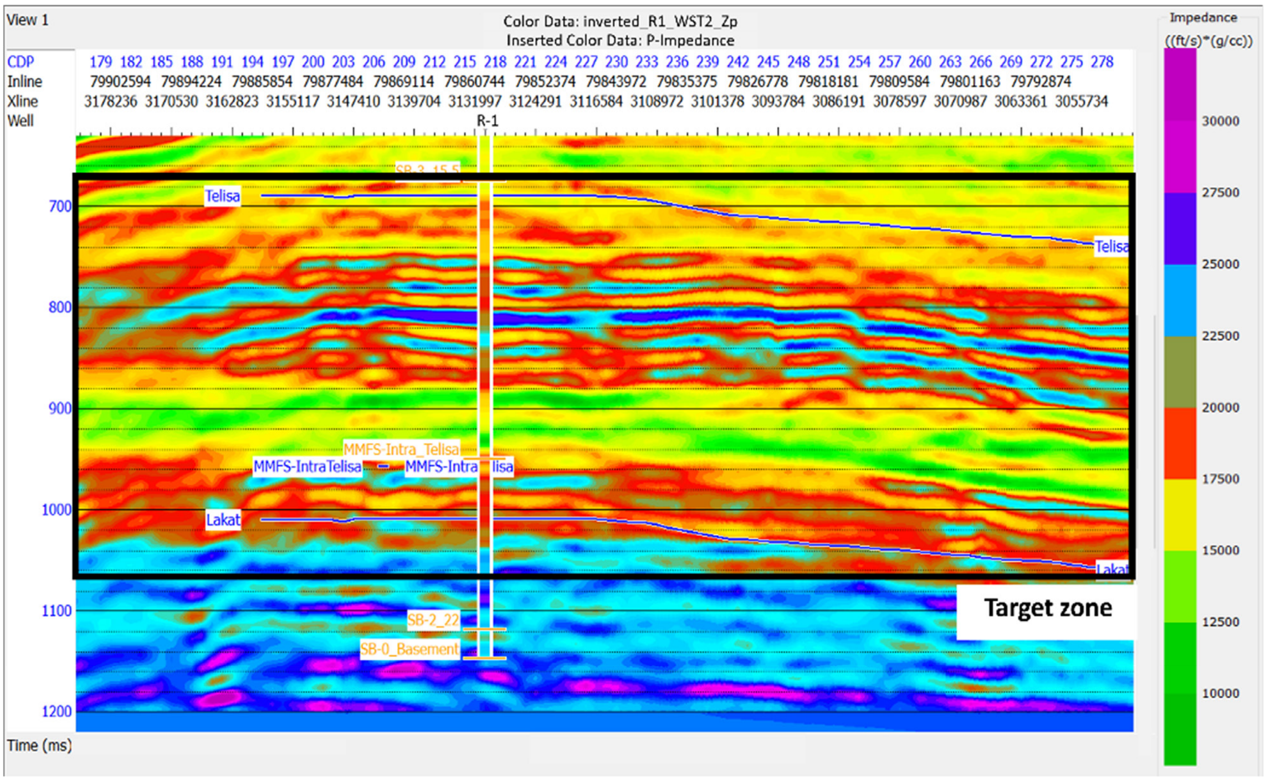

Figure 8. Seismic section of the telisa formation (in black box).

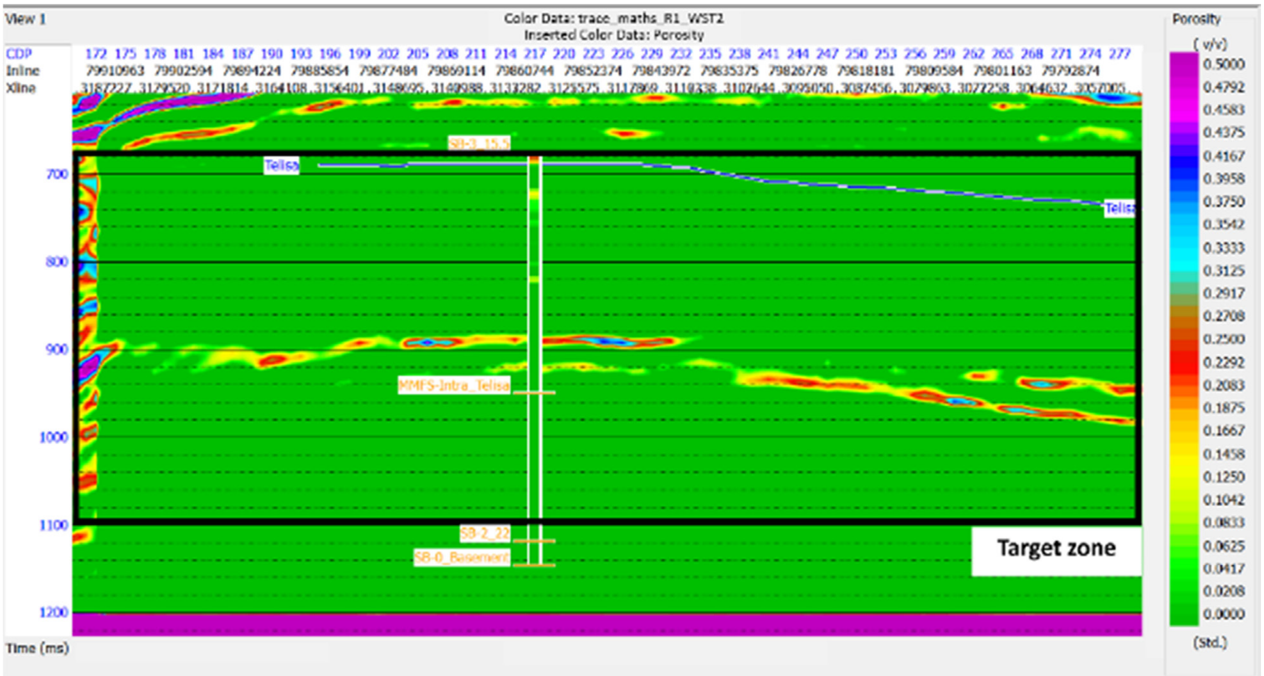

Figure 9. The porosity cross-section of the study area shows the dominance of shale rocks with low porosity

Figure 9 shows the porosity distribution in the Telisa Formation, with porosity values ranging from 0 to 0.5 v/v. The target zone in the Telisa Formation is dominated by low porosity, with a small intersection of medium porosity values. The shafted area is located at a depth of approximately 900 ms, with porosity values between 0.12 and 0.40 v/v.

This zone is categorized as moderate to well-porous (Koesoemadinata 1980), indicated by the yellow-to-blue color index. This is because the Telisa Formation contains not only shale lithology but also sandy shale, which has lower porosity.

CONCLUSION

The study of AI inversion applied to the Telisa Formation produced impedance values ranging from 12,000 to 27,000 (ft/s)(g/cc). These values are dominated by higher P-impedances, ranging from 23,000 to 27,000 (ft/s)(g/cc), which are associated with the dominance of shale layers, whereas lower P-impedance values, ranging from 12,500 to 22,000 (ft/s)(g/cc), correlate with sandy shale lithology.

Combining geophysical and well-log data shows that the lithology in the Akasia Area of the Telisa Formation is dominated by shale and sandy shale interbeds. Seismic inversion results, confirmed by well-log data, indicate no presence of gas fluids in the Telisa Formation despite the presence of low P-impedance anomalies. The low P-impedance value is more influenced by the rigidity parameter rather than incompressibility at the P-wave velocity value.

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GLOSSARY OF TERMS

Symbol	Definition	Unit
AI	Acoustic Impedance	(ft/s)(g/cc)
MBOPD	Thousand Barrels of Oil Per Day	
BSCF	Billion Standard Cubic Feet	
MSTB	Thousands of Stock Tank Barrels	
GR	Gamma Ray	API
CNL	Compensated Neutron Log	%

API	American Petroleum Institute	
MSFL	Micro Spherical Focused Log	ohm-m
LLS	Laterolog Shallow	ohm-m
LLD	Laterolog Deep	ohm-m

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