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Reservoir Characterization in The Airbenakat Formation Using Seismic Attributes and Proposed Well Determination in "X" Field Jambi Sub-Basin

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ABSTRACT

Jambi Sub-Basin is one of the prospective areas for oil and gas exploration in Indonesia. However, the reservoir interval in the study area is thinner than the vertical resolution of the seismic data, making it difficult to identify using conventional seismic interpretation methods. The study area is located within the Air Benakat Formation. This study applies seismic attribute analysis to characterize thin reservoir intervals that are difficult to resolve using conventional methods. The objectives of this study are to characterize the reservoir based on seismic attribute responses and to identify prospective locations for proposed wells in the X Field, Jambi Sub-Basin. Four seismic attributes, namely RMS amplitude, sweetness, envelope, and instantaneous frequency, were integrated to provide a comprehensive interpretation of reservoir characteristics. RMS amplitude and envelope attributes were used to identify high-amplitude zones and lithological boundaries, while sweetness and instantaneous frequency assisted in differentiating potential reservoir zones from non-reservoir intervals. The integration of these attributes enables the identification of zones associated with variations in lithology, porosity, and potential hydrocarbon occurrence. Based on the integration of depth maps and seismic attributes for RES#11 and RES#3, three proposed wells were identified within Prospects A, B, and C in the southwestern part of the field, at elevations ranging from 960 to 1,530 m. These prospects are associated with faults that may have acted as hydrocarbon migration pathways. The integrated seismic attribute analysis indicates significant hydrocarbon potential in the study area and provides a basis for identifying prospective drilling locations in the X Field.

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INTRODUCTION

Reservoir characterization involves identifying and evaluating reservoir properties using methods capable of representing subsurface conditions. Seismic data, particularly when integrated with well-log data, provide valuable information on lithological variations, reservoir distribution, structural features, and potential hydrocarbon-bearing intervals. Seismic attribute analysis is widely applied because it enhances specific characteristics of seismic reflections that may not be clearly visible on conventional seismic sections (Pamalik et al., 2020; Sukmono 2002).

The X Field in the Jambi Sub-Basin is a prospective area for oil and gas exploration, with the investigated reservoir occurring within the Air Benakat Formation. However, the reservoir thickness is below the vertical resolution of the available seismic data, making it difficult to distinguish the reservoir from adjacent layers due to seismic reflection interference. Farfour and Yoon (2014) demonstrated the potential of seismic attributes for interpreting ultra-thin reservoirs, while Manzoor et al. (2024) emphasized that characterizing sub-resolution thin beds remains a significant challenge in conventional seismic interpretation.

Previous studies have demonstrated the application of seismic attributes for hydrocarbon reservoir characterization. Pamalik et al. (2020) used the sweetness attribute combined with acoustic impedance inversion to characterize hydrocarbon reservoirs, demonstrating the usefulness of seismic attributes in identifying reservoir characteristics and potential hydrocarbon zones. Similarly, studies in the Jambi Sub-Basin have applied RMS amplitude attributes to identify potential hydrocarbon-bearing zones, while other studies have integrated seismic attributes such as RMS amplitude, sweetness, and envelope to investigate reservoir distribution and hydrocarbon potential in the Air Benakat Formation. These studies demonstrate the effectiveness of individual or combined seismic attributes for reservoir interpretation. However, the application of multiple seismic attributes specifically for characterizing reservoir intervals with thicknesses below seismic vertical resolution remains relatively limited, particularly when the attribute responses are integrated to support the identification of prospective drilling locations.

This limitation represents an important research gap because sub-resolution reservoir intervals may not produce clearly separated seismic reflections, making their identification using conventional amplitude-based interpretation difficult. Different seismic attributes respond to different characteristics of the seismic signal. RMS amplitude and envelope can emphasize amplitude variations and reflection strength, whereas sweetness incorporates amplitude and frequency characteristics that can enhance the visualization of subtle geological features. Instantaneous frequency provides complementary information related to changes in the frequency content of the seismic signal and may assist in identifying variations associated with lithology and thin-bed responses. Therefore, integrating these attributes can provide a more comprehensive interpretation than relying on a single attribute. In this study, RMS amplitude, sweetness, envelope, and instantaneous frequency are integrated to characterize thin reservoir intervals and identify subtle subsurface anomalies that may not be clearly visible on conventional seismic sections.

The integration of these seismic attributes with depth structure maps is subsequently used to identify prospective reservoir zones and evaluate their relationship with structural features, particularly faults that may influence hydrocarbon migration and trapping. This integrated approach is expected to improve the interpretation of thin reservoir intervals in the X Field and provide a geological basis for selecting prospective drilling locations. Therefore, the objectives of this study are to characterize the reservoir based on the responses of RMS amplitude, sweetness, envelope, and instantaneous frequency attributes and to determine prospective locations for proposed wells in the X Field, Jambi Sub-Basin.

Regional geology

Geographically, the Jambi Sub-Basin is bounded by the Tigapuluh Mountains to the north, the Lampung Highlands to the south, the Sunda Shelf to the east, and the Barisan Mountains to the west (Figure 1). Its main structure is a system of horst dan graben formed during the Paleogene. Horst dan graben trend northeast-southwest.

The geology of the South Sumatra Basin was formed by tectonic activity closely related to the north-northeast-trending Indo-Australian Plate. This plate shift zone covers the western part of Sumatra Island and the southern part of Java Island. Horst uplifted the basement layer forming the Merang Highland and Ketaling Highland, while the graben system formed the Ketaling Deep and Merang Deep (Sugiharto et al., 2023).

Stratigraphy

The Jambi Sub-Basin was formed through geological process that occurred during a transgressive phase followed by a regressive phase. The lower part of the basin covers the transgressive phase, consisting of the Talang Akar, Baturaja, and Gumai Formations. Meanwhile, the upper part of the basin covers the regressive phase with the Airbenakat, Muara Enim, and Kasai Formations. In addition, there is also the Lahat Formation and older rock layers, known as the older Lemat, which were deposited prior to the main transgressive phase (Ginger & Fielding 2005).

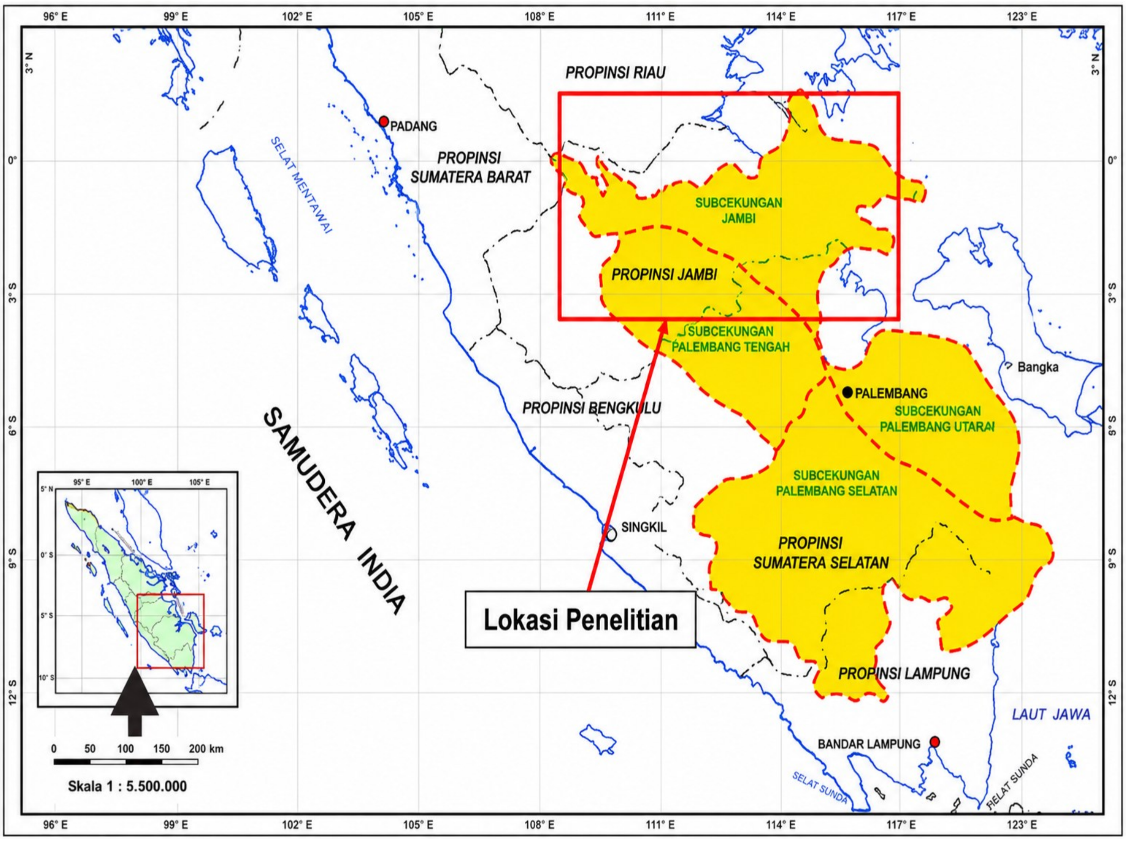

Figure 1. Map of the Jambi Sub-Basin Location (Panggabean & Lauti 2012).

The study location is in the Airbenakat Formation, as shown in (Figure 2). The Airbenakat Formation is one of the geological units found in the South Sumatra Basin, Indonesia. This formation was formed during the Middle to Late Miocene and is known as the main source of hydrocarbons in the region. This formation consists of clastic sedimentary rock layers, such as sandstone, claystone, shale, and conglomerate. The depositional environment of the Airbenakat Formation typically includes deltas, coastal zones, and shallow marine settings, making this formation an important exploration target for oil and gas as a reservoir.

Seismic reflection

The seismic reflection method is a geophysical technique that uses waves reflected from subsurface boundaries due to contrasts in rock physical properties. Seismic waves are generated using sources such as dynamite or vibrators and recorded by geophones or hydrophones to characterize subsurface geological conditions (Oktavinta 2008).

Seismic waves consist of body waves, including P-waves and S-waves, and surface waves, including Rayleigh and Love waves (Maharani 2018). Seismic attributes are quantitative parameters derived from seismic traces, such as amplitude, phase, and frequency, that enhance subsurface interpretation and provide information related to lithology, reservoir properties, and potential hydrocarbon occurrences (Barnes 1999).

In this study, variance and ant-tracking attributes are used to enhance seismic discontinuities and support fault interpretation (Taner 2001; Antrett 2013), while RMS amplitude is used to identify strong amplitude variations associated with lithological changes and potential reservoir zones (Hadi et al., 2006). Sweetness combines amplitude and frequency information to enhance subtle seismic features and identify potential reservoir and hydrocarbon-bearing zones (Arifuddin 2017). Instantaneous frequency represents temporal variations in seismic frequency and provides complementary information related to lithological changes, layer thickness, and potential hydrocarbon-bearing intervals (Taner et al., 1979).

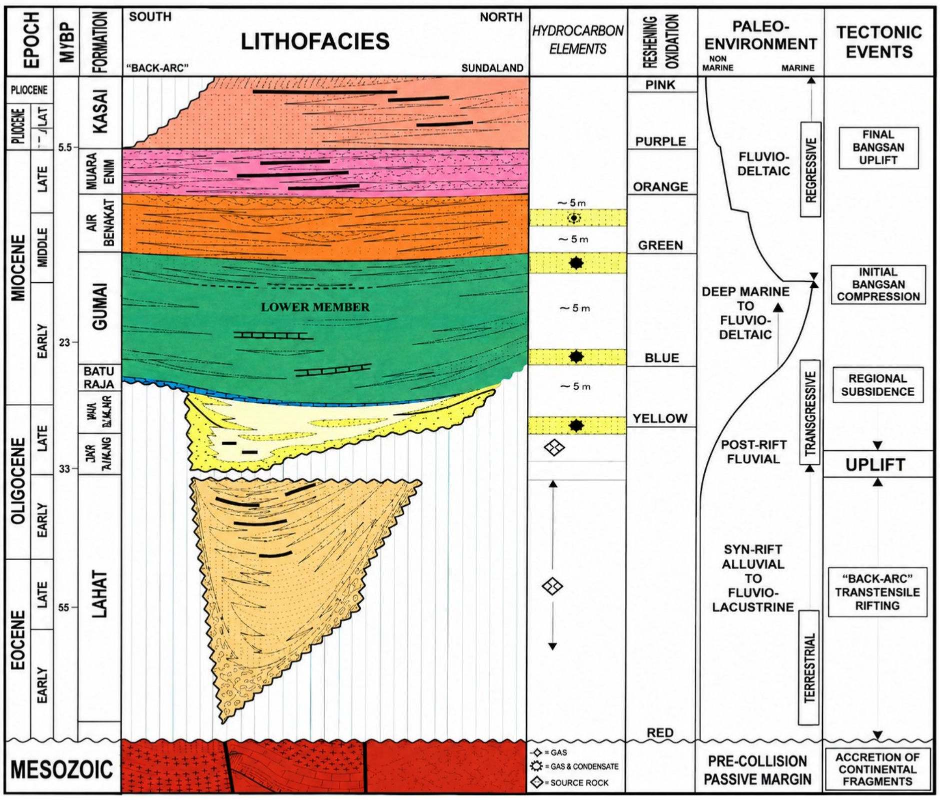

Figure 2. Stratigraphy of the Jambi Sub-Basin (PetroChina International Jabung 2017).

The envelope, or reflection strength, represents the magnitude of the seismic trace independent of phase and is useful for highlighting amplitude contrasts, lithological boundaries, and anomalous reflection zones associated with reservoir characteristics. Well logging is a formation evaluation technique that records the physical properties of subsurface rocks using various logging tools, and the integration of different logs enables qualitative and quantitative interpretation of lithology, reservoir properties, and potential hydrocarbon-bearing intervals (Zain & Rahman 2021).

METHODOLOGY

This study used secondary data obtained from PT Pertamina Hulu Rokan Zone 1 Jambi, located at Jalan Lirik No. 1, Komperta Kenali Asam, Jambi City, Jambi Province. The dataset consisted of 3D post-stack time-migrated (PSTM) seismic data in SEG-Y format and well-log data from five wells (Figure 3). Data processing and interpretation were performed using HRS 10.6 and Petrel 2017, while Microsoft Office, Microsoft Excel, and Notepad were used for data preparation and supporting analysis. The availability of well data for each well is presented in Table 1, including gamma ray (GR), caliper (CALI), spontaneous potential (SP), bulk density (RHOB), neutron porosity (NPHI), deep laterolog resistivity (LLD), sonic travel time (DT), and checkshot data.

Data processing

The research workflow began with well-log analysis to identify potential sandstone reservoir intervals and establish the upper and lower boundaries of the target reservoir. The identified reservoir thickness was then evaluated through tuning-thickness analysis to determine whether the interval could be resolved by the available seismic data. Because the target reservoir thickness is below the estimated seismic vertical resolution, seismic attribute analysis was applied to enhance its interpretation.

The seismic data were subsequently prepared and interpreted through wavelet extraction and well-to-seismic tying. A representative wavelet was extracted from the well with the highest correlation to the seismic trace and used to generate a synthetic seismogram from the sonic and density logs. Checkshot data were incorporated to establish the depth-to-time relationship, and stretching and squeezing adjustments of up to 10 ms were applied to obtain an optimal correlation between the synthetic and observed seismic traces.

Fault and horizon interpretation was then performed across the 3D seismic volume. Fault discontinuities were identified using the variance attribute and enhanced using ant-tracking, while the target reservoir horizon was interpreted based on seismic reflector continuity and the well-to-seismic tie. The interpreted horizon was used to

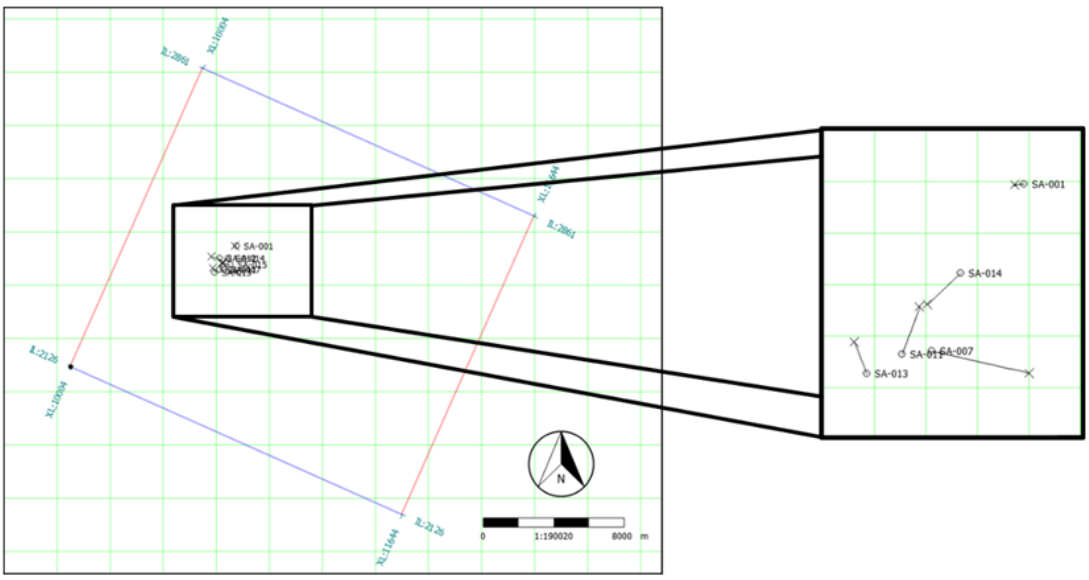

Figure 3. Research area base Map.

generate time-structure and depth-structure maps, which were subsequently integrated with the fault framework to evaluate structural configurations and potential trapping features.

Crossplot analysis was conducted using selected well-log parameters to distinguish reservoir and non-reservoir intervals and establish appropriate cut-off values. Seismic attribute analysis was then performed over the target reservoir interval using RMS amplitude, sweetness, envelope, and instantaneous frequency.

These attributes were selected to provide complementary information on amplitude and frequency variations associated with lithological and reservoir characteristics. Finally, the attribute maps were integrated with the well-log interpretation, depth-structure map, and fault framework to delineate prospective reservoir zones and determine proposed well locations in the X Field, Jambi Sub-Basin.

RESULT AND DISCUSSION

Determination of target zones based on log data

In this study, the target reservoir interval was defined using marker data provided by PT Pertamina Hulu Rokan Zone 1 and identified through the integrated analysis of Gamma Ray, resistivity, and porosity logs. Gamma Ray cut-off analysis was subsequently performed for each well to quantitatively distinguish shale- and sand-dominated intervals within the target zone.

The cut-off values were determined based on the maximum and minimum Gamma Ray

Table 1. Well Data.

Atribut log	Well Number				
	SA-1	SA-7	SA-11	SA-13	SA-14
GR	✓	✓	✓		✓
CALI	✓	✓	✓	✓	✓
SP	✓	✓	✓	✓	✓
RHOB	✓	✓	✓	✓	✓
NPHI	✓	✓	✓	✓	✓
LLD	✓	✓	✓	✓	✓
DT	✓	✓	✓	✓	✓
CS		✓			

Table 2. Tuning Thickness Calculation Results for the Five Wells

Sumur	Zona target	Top (m)	End (m)	Ketebalan (m)	Frekuensi (Hz)	Av. Vel (m/s)	λ (m)	1/4 λ (m)
SA-001	RES#11 - BOT#11	1044.27	1062.89	18.62	14	2256.652823	161.1894873	40.29737183
	RES#3 - BOT#3	1556.61	1568.25	11.64	14	2518.597412	179.8998151	44.97495378
SA-007	RES#11 - BOT#11	1051.43	1074.18	22.75	14	2196.462252	156.8901608	39.22254021
	RES#3 - BOT#3	1675.12	1687.46	12.34	14	2428.43012	173.4592943	43.36482358
SA-011	RES#11 - BOT#11	1032.7	1068.22	35.52	14	2198.379745	157.0271246	39.25678116
	RES#3 - BOT#3	1602.72	1614.38	11.66	14	2419.487595	172.8205425	43.20513562
SA-013	RES#11 - BOT#11	1019.03	1049.27	30.24	14	2229.869562	159.2763973	39.81909932
	RES#3 - BOT#3	1583.06	1596.27	13.21	14	2438.400787	174.1714848	43.54287119
SA-014	RES#11 - BOT#11	1041.43	1069.5	28.07	14	2211.248947	157.9463534	39.48658835
	RES#3 - BOT#3	1583.43	1592.59	9.16	14	2413.79641	172.4140293	43.10350733

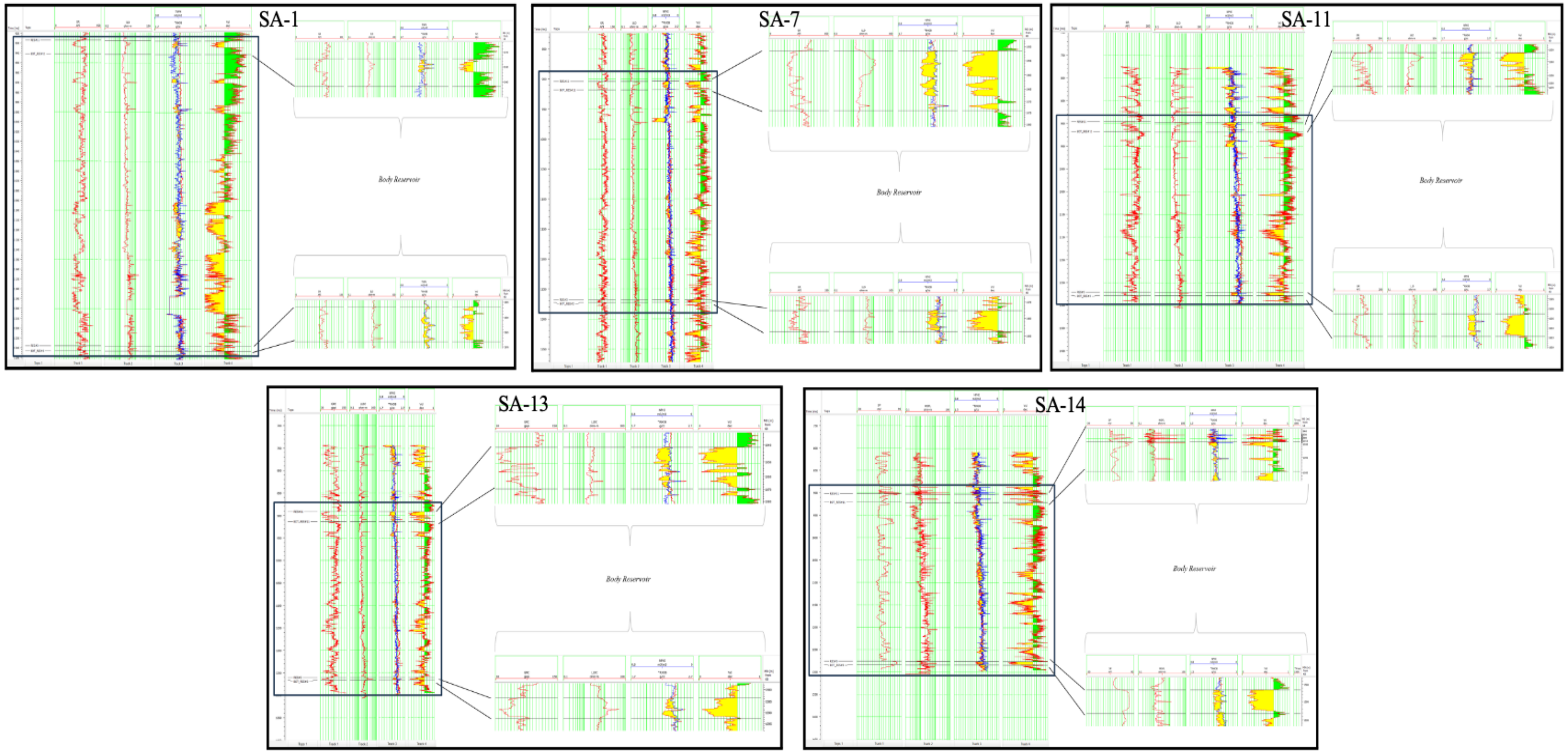

Figure 4. Determination of target zones based on log data.

responses, representing the shale and clean-sand baselines, respectively. High Gamma Ray values were interpreted as shale-rich intervals, whereas lower values indicated sand-dominated intervals. The resulting Gamma Ray cut-off values were then applied to classify the target formation into reservoir and non-reservoir intervals in the X Field, Jambi Sub-Basin.

Quick-look analysis of well SA-7 was performed to identify potential hydrocarbon-bearing reservoir intervals using Gamma Ray, resistivity, density, and neutron porosity logs. As shown in Figure 4, the target interval extends from 880ms to 1.300ms in the time domain and from 1.000m to 1.760m in depth. Low Gamma Ray responses indicate sand-dominated and potentially permeable intervals, whereas higher responses represent shale-rich layers. Potential hydrocarbon-bearing zones are characterized by relatively high resistivity responses accompanied by a density–neutron crossover. Two significant crossover intervals were identified at depths of 1.051,38m – 1.074,25m and 1.675,25m – 1,687,45m, indicating potential reservoir zones within the study area.

Tuning thickness analysis

Tuning thickness analysis was conducted for each well to evaluate the seismic resolvability of

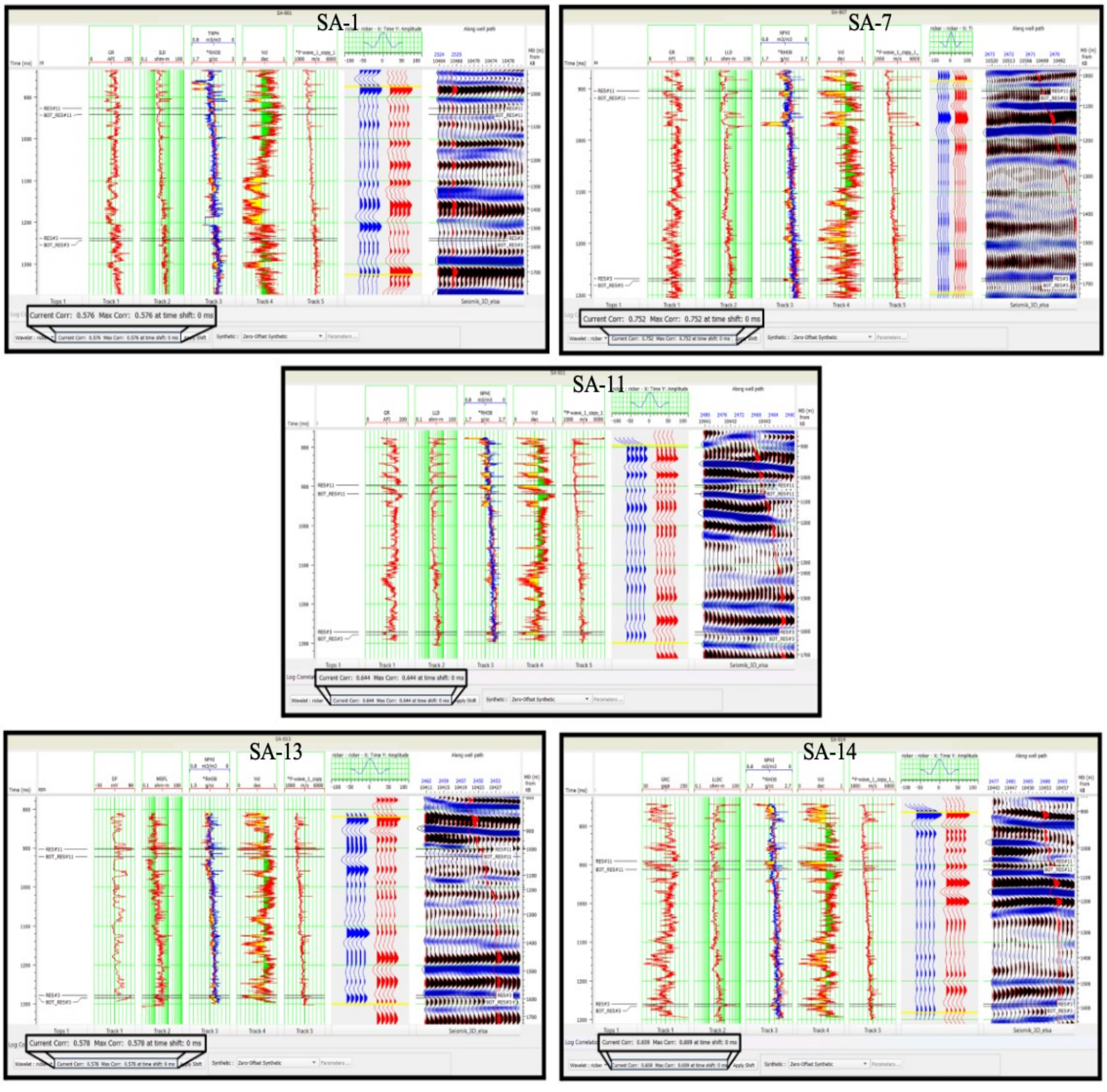

Figure 5. Well Seismik Tie for Wells SA-1, SA-7, SA-11, SA-13, and SA-14

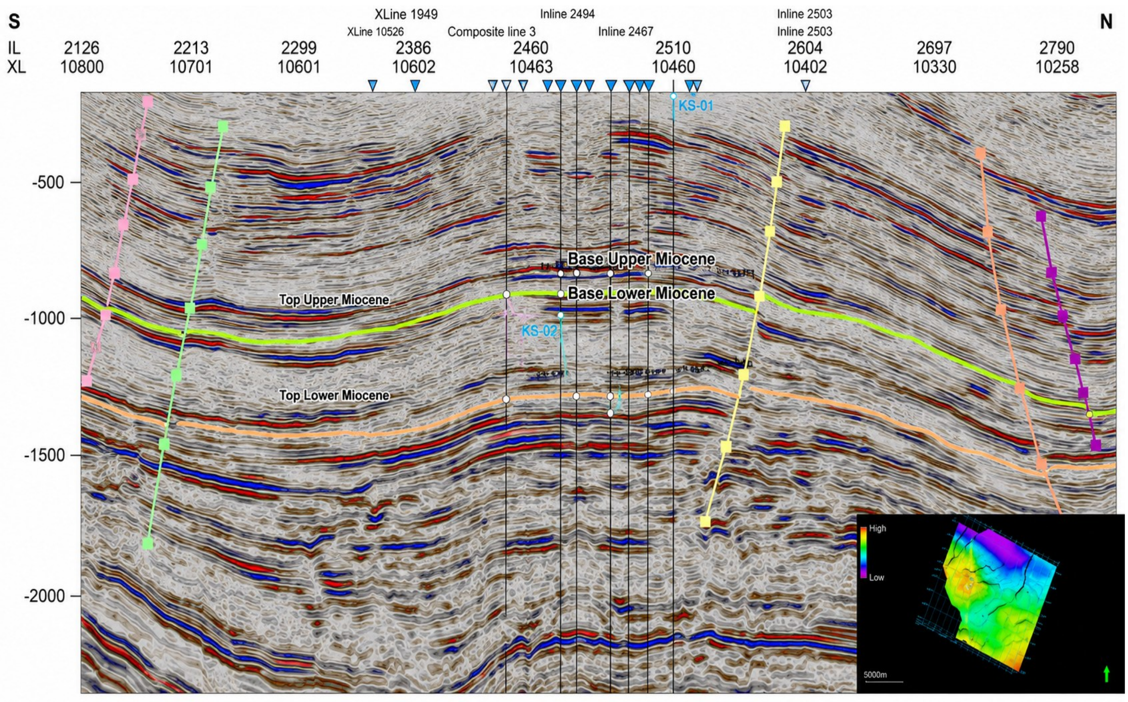

Figure 6. Picking horizons and faults across 5 wells.

the target reservoir. The interpreted sandstone reservoir thickness ranges from approximately 9 to 35 m, which is below the estimated seismic vertical resolution (λ/4). Therefore, the target reservoir is difficult to resolve on conventional seismic sections because the top and bottom reflections interfere and appear as a single composite reflector when the layer thickness is below the tuning thickness.

Wavelet extraction

Wavelet extraction was performed to obtain a representative wavelet that provides the best match with the seismic data and subsurface conditions of the study area. A Ricker wavelet with a duration of 100ms and a dominant frequency of 14 Hz was selected based on its compatibility with the seismic response. This wavelet was subsequently used to generate the synthetic seismogram for the well-to-seismic tie process.

Well seismik tie

Well to seismic tying is the process of correlating well-log data with seismic data to establish a relationship between the depth and time domains. Well data are recorded in depth (m), whereas seismic data are represented in two-way travel time (ms). This process aims to accurately correlate well-log information with seismic reflections and calibrate the position of geological horizons or formation tops on seismic sections.

Picking fault and picking horizon

Following the completion of well-to-seismic ties, horizon and fault picking was performed. Horizon picking is a crucial step in seismic interpretation to delineate the continuity of stratigraphic markers. In this study, horizon interpretation focused on two target intervals within the Airbenakat Formation: RES#11 (the upper layer) and RES#3 (the lower layer). The picking was guided by well markers established during the tying process to define distinct boundaries between rock layers.

Figure 6 displays the results of horizon and fault picking along a north-to-south seismic section intersecting all four wells. Horizon markers across the wells demonstrate clear continuity within the RES#11 and RES#3 layers, establishing them as primary references for the stratigraphic framework. This consistency confirms the successful integration of well and seismic data, providing a robust foundation for geological interpretation and reservoir modeling. Establishing this structural and stratigraphic framework delivers crucial insights for evaluating hydrocarbon potential, delineating reservoir zones, and optimizing drilling strategies—underscoring the vital role of horizon picking in oil and gas exploration.

Time structure and depth structure maps

The subsurface geological mapping process was carried out following the completion of fault and horizon interpretations in the study area. The results are presented as time-structure and depth-structure maps derived from seismic data. The RES#11 time-structure map displays structural depths ranging from a low contour of -1450ms (purple) to a high contour of -1050ms (orange) (Figure 7). Meanwhile, the RES#3 time-structure map exhibits a lowest contour of -1650ms and a highest of -1350ms (Figure 8). Together, these maps reveal a horst and graben structural framework extending from northeast to southwest, bounded by normal faults on both sides. This fault pattern reflects tectonic activity that significantly influenced the structural morphology of the targeted layers.

Overall, as shown in Figures 7 and 8, both depth-structure maps exhibit geological trends consistent with those observed on the two-way time structure maps. The depth-structure maps reveal several structural traps, specifically anticlinal and fault-bounded traps. The anticlinal closures are indicated by orange-colored regions at depths of approximately 960m in the RES#11 layer and 1.440m in the RES#3 layer, extending in a northeast–southwest orientation. Meanwhile, the fault traps are delineated by white lines.

Mapping using time-domain seismic attributes

- Seismic Attribute RMS Amplitude

  Essentially, this RMS amplitude slice was generated using a window extending 3 ms above and 10 ms below the horizon; the analysis reveals high-amplitude anomalies, as shown in Figure 9. The RMS attribute results for the RES#11 and RES#3 layers indicate that zones exhibiting extreme reflection coefficient contrasts are concentrated in specific areas. High RMS anomaly values in these layers range from 7.000 to 17.000 (arbitrary units), represented by yellow-to-red color gradients on the map.

- Seismic Attribute Sweetness

  The sweetness attribute was extracted using a window of 3ms above and 10ms below the horizon, with color variations reflecting rock properties and hydrocarbon potential. In the RES#11 and RES#3 layers (Figure 10), the sweetness attribute highlights several prospective hydrocarbon-bearing zones within Field 'X'. High anomaly values (ranging from 2.000 to 6.250) at the top of the Airbenakat Formation are represented by yellow-to-red hues. Notably, a high-sweetness zone of interest is located southeast of the wells, adjacent to a deep-seated fault that likely facilitated hydrocarbon accumulation across both the RES#11 and RES#3 intervals.

- Seismic Attribute Envelope

  In the attribute slice shown in Figure 11, this study used a window width extending 3 ms above and 10ms below horizons RES#11 and RES#3. This analysis reveals the distribution of sandstone reservoirs in the study field, with high contrast values ranging from 9.000 to 21.000 indicated by a color gradient shifting from yellow to red.

- Seismic Attribute Instantaneous Frequency

  Low-frequency anomalies typically indicate unconsolidated sandstones with potential hydrocarbon content as well as fractured zones. Additionally, this attribute helps delineate variations in layer thickness and massive bedding geometries (Figure 12). Extracted using a window extending 3ms above and 10ms below horizons RES#11 and RES#3, the attribute slice reveals a prominent low-frequency zone (0–15 Hz) in the eastern part of the study area. Represented by purple-to-light-blue hues, this anomaly suggests the presence of hydrocarbons.

Map integration for proposed well determination

The proposed well placement analysis was carried out by integrating five key maps: depth-

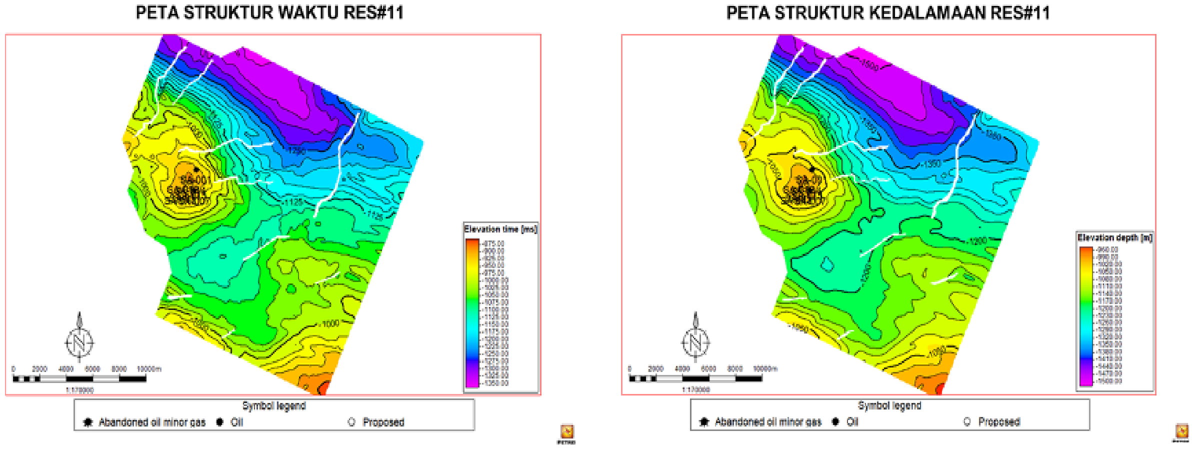

Figure 7. Time to Depth conversion RES#11

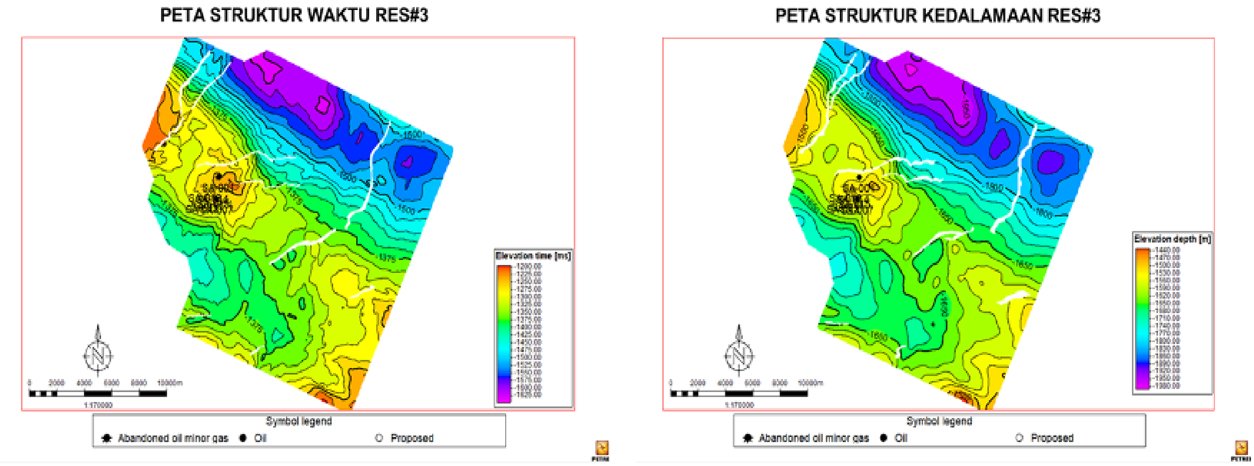

Figure 8. Time to Depth conversion RES#3

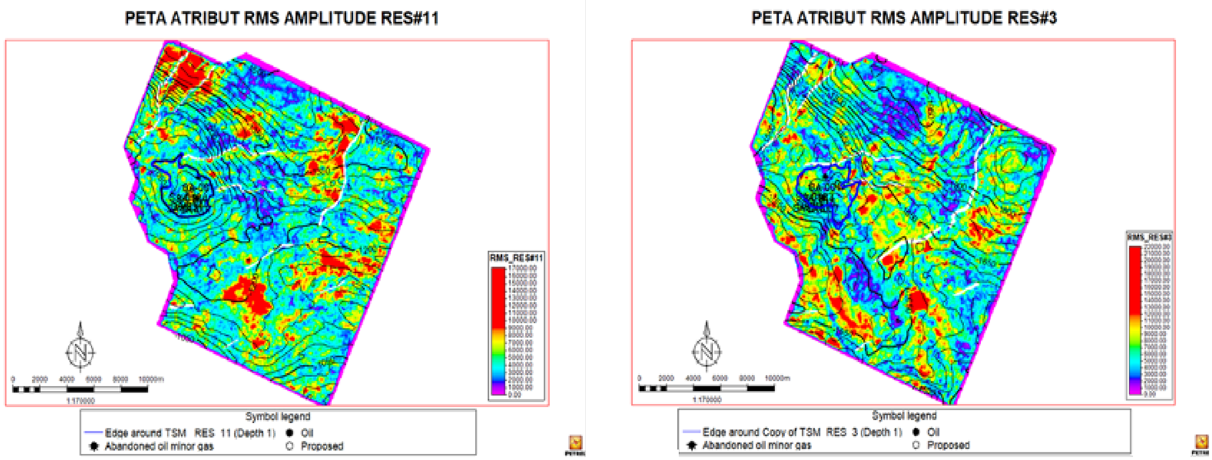

Figure 9. RMS Attribute Map of the RES#11 and RES#3 Formations.

structure, RMS amplitude, sweetness, envelope, and instantaneous frequency. Integrating these maps aims to pinpoint prospective hydrocarbon-bearing locations based on the combined responses of the extracted attributes across the study area.

The depth structure interpretation results show that the hydrocarbon reservoir prospect is located in a high zone that functions as an accumulation area. Anticlinal structures bounded by normal faults form structural hydrocarbon traps due to compressional and extensional forces during the formation of the Jambi Sub-Basin. Prospective areas are marked by contour lines higher than well SA-014 (Proposed) to identify potential locations, thereby reducing risk and improving drilling planning efficiency.

Based on Figure 13, the development well location on horizon RES#11 shows that hydrocarbons are estimated to migrate from the northeast (lower contour) toward the southwest (higher contour). This occurs because the density of hydrocarbons is lower than that of the surrounding rock, so hydrocarbons tend to move toward higher areas and eventually accumulate there. From this analysis, it can be concluded that the next development well should be placed in the high area to maximize the potential for hydrocarbon discovery.

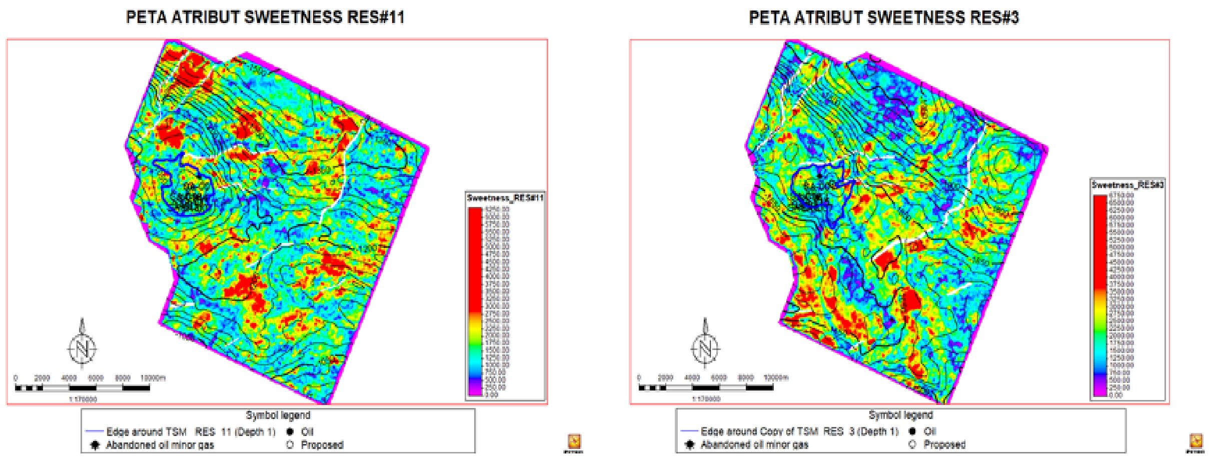

Figure 10. Sweetness Attribute Map of the RES#11 and RES#3 Formations

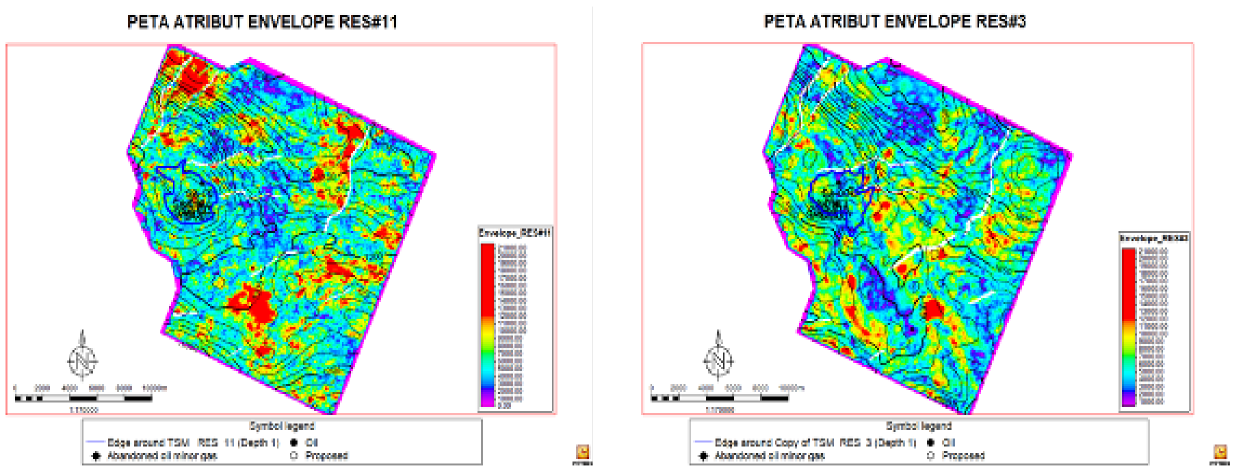

Figure 11. Envelope Attribute Map of the RES#11 and RES#3.

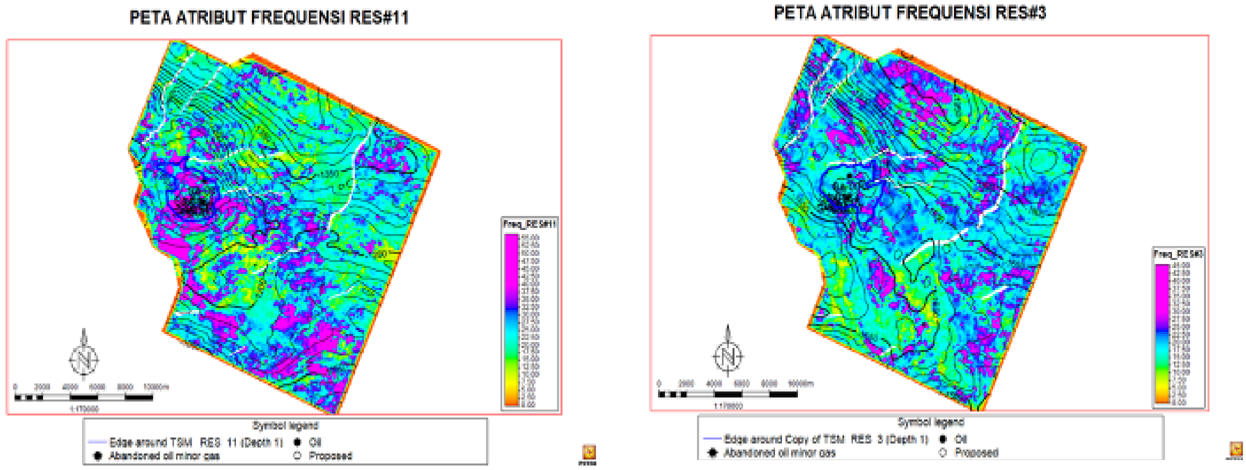

Figure 12. Instantaneous Frequency Attribute Map of the RES#11 and RES#3 Formations.

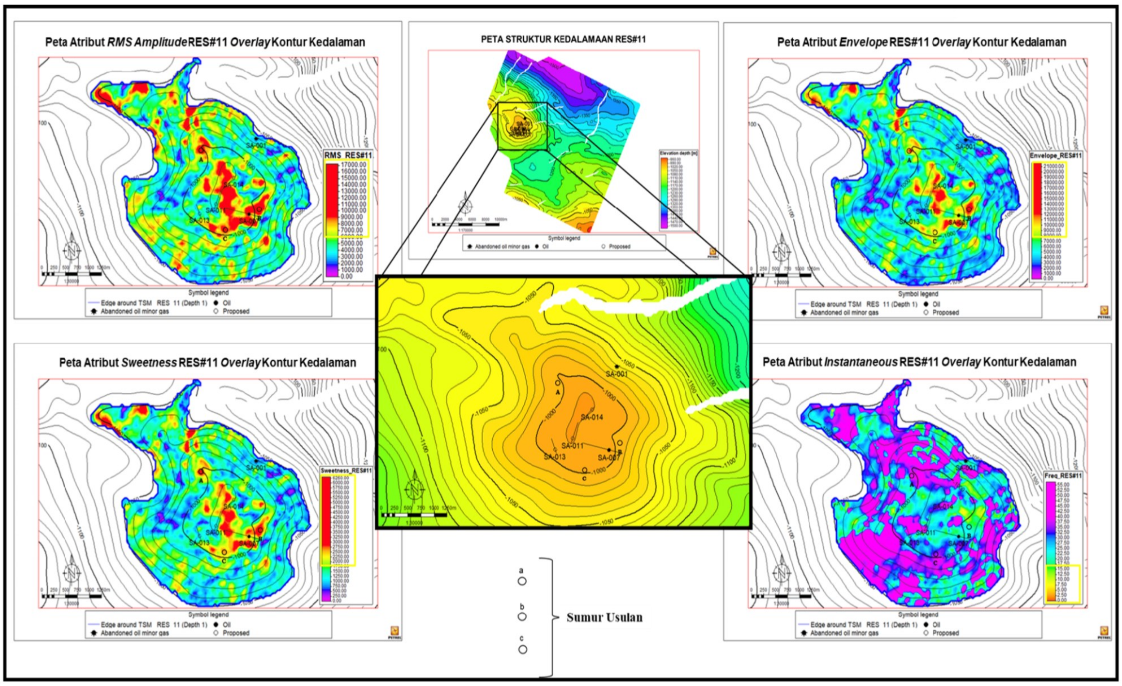

Figure 13. Integration of the five maps on the horizon RES#11 for proposed well determination.

Proposed wells 1-3 are planned in prospect areas A, B, and C at an elevation of 960-1050 meters to the southwest, which is influenced by faults important for hydrocarbon migration toward higher zones. Based on the four attribute maps (RMS amplitude, envelope, sweetness, and instantaneous frequency), the hydrocarbon potential in this area is quite significant. The geological structure supports hydrocarbon accumulation, making this location promising for the exploration drilling stage to take advantage of the hydrocarbon migration pathway through the fault.

CONCLUSION

The integration of four seismic attributes-RMS amplitude, sweetness, envelope, and instantaneous frequency-provides a comprehensive basis for characterizing the target reservoir. The results indicate that the interpreted reservoir is generally associated with relatively high-amplitude responses,

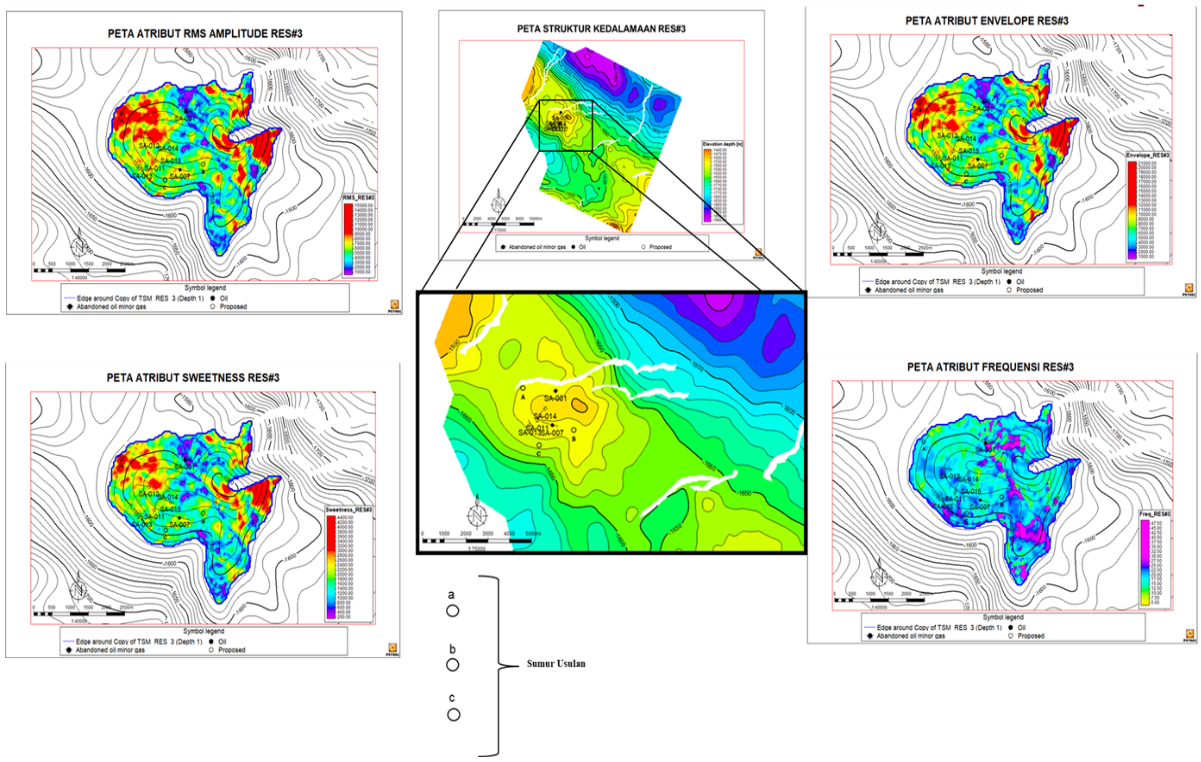

Figure 14. Integration of the five maps on the horizon RES#3 for proposed well determination

represented by bright-spot and sweet-spot anomalies, while the frequency-based attribute shows relatively low-frequency responses. The prospective reservoir zone in the X Field occurs at depths of approximately 960–1,530 m and exhibits a southwestward trend.

The integration of the depth-structure map with the RMS amplitude, sweetness, envelope, and instantaneous frequency maps for the RES#11 and RES#3 intervals was used to delineate prospective areas and determine three proposed well locations (Wells 1–3) within Prospects A, B, and C. These prospects are located within the interpreted depth range of 960–1,530 m and are structurally influenced by faults that may act as potential hydrocarbon migration pathways. The consistent anomalous responses observed across multiple seismic attributes, together with favorable structural positions, indicate that these areas have potential for hydrocarbon accumulation and provide a basis for the proposed well locations.

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DECLARATIONS

Author contribution

Elsa Laiyanti: Conceptualization, methodology, data curation, analysis, investigation, visualization, and writing original draft. Bagus Adhitya: Supervision, methodology, validation, conceptualization, writing review and editing. Juventa: Supervision, validation, review and editing. Muhammad Subhan: Supervision, validation, and technical guidance.

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Competing interest

The authors declare that we have no competing interests that could have influenced the research, analysis, interpretation, or publication of this study.

The use of AI or AI-assisted technologies

During the preparation of this manuscript, AI-assisted tools were used only for language refinement, including improving grammar, clarity, and readability. All scientific content, interpretations, and conclusions were developed and verified by the authors.

GLOSSARY OF TERMS & SYMBOLS

Terms & Symbols	Definition	Unit
GR	Gamma Ray, Logging tool used to identify shale content and distinguish between shale-rich and clean formations.	°API
CALI	Caliper, logging tool that measures the diameter and shape of the borehole to identify borehole diameter	in
SP	Spontaneous Potential, logging tool used to identify permeable formations and estimate formation water salinity	mV
RHOB	Bulk Density, Logging tool used to estimate porosity and identify lithology	g/cm3
NPHI	Neutron Porosity, Logging tool used to estimate formation porosity	%
LLD	Deep Laterolog Resistivity, Logging tool used to evaluate formation fluids and hydrocarbon saturation.	ohm·m
DT	Sonic Travel Time, Logging tool used to estimate porosity and identify lithology.	µs/ft
RMS	Root Mean Square Amplitude,	

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