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Evaluation of Structural Features and Hydrocarbon Reservoir Potential of the Baturaja Formation Using Seismic Envelope and Sweetness Attributes

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Abstract

The Afara Field is located around the South Sumatra Basin, which is estimated to contain oil and gas hydrocarbon deposits. The method that can be used for hydrocarbon reserve exploration is the seismic method. Interpretation analysis is carried out by analyzing seismic attributes to determine the amplitude value, shape, and position of seismic waves to identify depositional environments, fluvial or channels, carbonate buildups, to detect fractures and faults, and to provide a direct hydrocarbon indicator (DHI). In this study, the seismic attributes used are the envelope and sweetness attributes to identify the presence of reservoirs, and the ant-tracking attribute is used to identify fault structures around the study area. The results obtained from the analysis carried out on the envelope attribute are the presence of hydrocarbon deposit areas seen from the bright-spot which indicates that the resulting amplitude value is high. The amplitude value has a range of values around 280,000 ms to 440,000 ms located around the UPI-40 and UPI-60 wells. This is validated by the sweetness attribute, which is characterized by the presence of a sweet spot with a value ranging from 60,000 ms to 80,000 ms. The results of the geometric attribute analysis revealed the presence of faults in the study area.

Keywords: Seismic Attributes, Envelope, Sweetness, Ant-tracking, Baturaja Formation.

INTRODUCTION

Oil and natural gas are the world's primary raw materials for many industries, and Indonesia has significant potential of it. Total domestic oil production is 278.01 barrels, while the total amount of oil imported by the government of Indonesia from oil-producing countries is 165.04 barrels/year (Erdiwansyah et al., 2021). Oil and gas exploration activities are essential to prevent a decline in oil and gas production. Exploration takes years, one method commonly used for hydrocarbon exploration is seismic exploration (Adesanya et al., 2021). Seismic is an active geophysical method that uses elastic waves to determine the condition of the Earth's subsurface. Wave originate from a source, propagate through the subsurface, and are recorded by detectors in the form of geophones, which measure ground deformation. Ground deformation has a time function, commonly referred to as a seismic trace (Goda, 2017).

One seismic method used in exploration activities is seismic attributes. Seismic attributes are used to more clearly identify faults and determine the location of hydrocarbon accumulations (Ibekwe et al., 2023). Seismic attributes can also be used for more accurate subsurface interpretation. The envelope and sweetness attributes are used to identify reservoirs around the study area. The envelope attribute is sensitive to amplitude changes associated with the characteristics of layers where hydrocarbons accumulate (Oumarou, S et al., 2021). The sweetness attribute is used to identify "sweet spots" with high amplitude and low frequency in seismic data to determine the presence of hydrocarbons (Emujakporue & Enyenihi, 2020). The sweetness attribute is a combination of the envelope and instantaneous frequency attributes (Pamalik et al., 2020). The ant-tracking attribute is used to clarify discontinuities within the seismic data within the study area (Xie et al., 2022).

The South Sumatra Basin is the result of subduction tectonic activity between the Indo-Australian Plate, which moves north to northeast. These activities can affect the rock conditions, morphology, tectonics, and structure of the basin (Bagha et al., 2014). The South Sumatra Basin is a basin with geological structures that play an active role in sediment deposition during the pre-rift, syn-rift, and post-rift phases. Geological structures are crucial elements in the petroleum system because they can act as traps and facilitate hydrocarbon migration (Luqman et al., 2019). The Afara Field is located within the South Sumatra Basin and is thought to contain hydrocarbon deposits. The target formation used in this study is the Baturaja Formation, which contains carbonate at the top and shale with thin limestone layers (Manwarjit, 2021).

Although seismic attributes are widely recognized as powerful tools for hydrocarbon exploration, their integrated application in the Afara Field has not been reported (Ologe & Olowokere, 2021). Seismic attributes like envelope and sweetness can dramatically enhance the visibility of hydrocarbon indicators by amplifying subtle amplitude and frequency variations (Oumarou, A et al. (2021); Ismail et al. (2020)). For example, Oumarou, A et al. (2021) showed that sweetness and envelope attributes delineate hydrocarbon-rich zones and bright spots (changes in acoustic impedance). Likewise, ant-tracking algorithms are well established for fault detection; Zhang et al. (2017) demonstrated that ant-tracking maps clearly resolve both major and minor fault networks, outperforming conventional interpretation. Bargees et al. (2023) similarly noted that envelope and sweetness provide “a clearer image” of subsurface fluid-related anomalies (e.g. gas chimneys) by highlighting contrasts between fluid and lithology. Despite these successes, no prior studies have combined envelope, sweetness and ant-tracking in the Afara Field’s Baturaja carbonates. In fact, most seismic-attribute work in South Sumatra has focused on clastic reservoirs, and published analyses of the Baturaja Formation have not employed these specific attributes. For instance, characterization of the Baturaja carbonate in adjacent fields (e.g. Soka Field) relied on well logs and cores, noting that 3D seismic resolution is poor in these carbonates (Miharno, 2017). This indicates a clear need: to apply advanced seismic attributes to the Baturaja limestones at Afara. In summary, an explicit gap exists in the Afara Field: the lack of an integrated attribute study using envelope, sweetness and ant-tracking to simultaneously image reservoirs and faults. The current work is designed to fill that gap.

Studies on regional geology, regional tectonics, and the petroleum system are crucial to support subsurface information surrounding the Afara Field (Abu et al., 2021). This study uses seismic envelope and sweetness attributes to determine the distribution of reservoirs around the Afara field and ant-tracking attributes to determine the faults around the Afara field.

METHODS

The research was conducted in the Afara field, which is included in the Palembang Sub-Basin, South Sumatra Basin, using secondary data managed by PT Pusat Kajian Geofisika Reservoir. The data used is 3D Post-Stack Time Migration (PSTM) seismic data with seg-y format that has an inline between 2095-2550 and a crossline around 10041-10341. This study has two well data, namely wells UPI-40 and UPI-60 with complete log data as presented in Table 1.

The target formations used in this study are the Baturaja Formation, Talang Akar Formation, and SB-10 Formation. The data processing process begins with the input of seismic data in the (.sgy) format and well data in the (.las) format. Before use, well data should be checked for completeness of the log data, well position data (elevation data, well coordinates, and parameter units). After all seismic and well data are input, wavelet extraction and well seismic tie are performed using CCH HRS 10.3.2 software. The wavelet extraction process is carried out to determine the type of wavelet to be used. Parameters that must be considered when performing wavelet extraction are frequency domain, phase, and sample rate.

After the wavelet extraction process is completed, the well seismic tie process is carried out in several stages, including data preconditioning using well log data in the form of gamma ray logs, sonic logs, density logs, and checkshot data. Afterward, sonic calibration is performed to correct the checkshot data, which will be used to correlate the time-domain seismic data with the depth-domain well data. Following sonic calibration, synthetic generation is performed. This process involves adjusting the shifting of the seismic trace and synthetic seismogram to ensure they are at the appropriate depth and produce a good correlation. A good correlation is considered when the value approaches 1 with a time shift close to 0.

The next data processing step is horizon picking and fault picking, which are performed on the seismic trace. Fault picking is performed to identify reflector discontinuities due to faults. Horizon picking is used to create surfaces and facilitate interpreters in displaying the geological structures in the study area. During horizon picking, the peak and trough

Table 1. Completeness of well data log

Name of The Well	Log				
	Checkshot	RHOB	GR	DT	LLD
UPI-40	✓	✓	✓	✓	✓
UPI-60	✓	✓	✓	✓	✓

*RHOB : Bulk density DT : P-Sonic/P-Wave
GR : Gamma Ray LLD : Resistivity

positions must align with the top formation markers. Horizon and fault picking were performed inline and crossline along the BRF, TAF, and SB-10 layers in increments of 10. A total of 171 inline boundaries were used, approximately 2164-2335, and an x-line boundary was used at 10241.

After fault and horizon picking, a structural framework and time structure map were created. The structural framework was used to model the fault picking results and then interpret them using a time structure map. The time structure map was created to depict the subsurface geological structure of the Afara field in the time domain.

The next step in data processing was the application of seismic attributes to determine the distribution of hydrocarbon reservoirs and faults in the study area. The seismic attributes used in this study were envelope, sweetness, and ant-tracking. The envelope attribute is used to identify the presence of hydrocarbons in the form of bright-spot points using the default window size parameter of 33. The sweetness attribute is used to identify "sweet spots" that have high amplitude and low frequency in seismic data to determine the presence of hydrocarbons (Emujakporue & Enyenihi, 2020). The sweetness attribute is a combination of the envelope attribute and the instantaneous frequency attribute. The next attribute used is the ant-tracking attribute for clarify discontinuities the fault zones around the research location (Xie et al., 2022).

RESULTS AND DISCUSSION

Wavelet Extraction

Based on the data processing that has been done, this study uses a zero-phase wavelet type that has energy concentrated in the center. Wavelet extraction is a static wavelet based on the target zone. Figure 1 shows the results of the wavelet extraction that has been done. Figure 1A shows the wavelet response to time. Figure 1B shows the wavelet response to frequency.

Picking Fault and Picking Horizon

The results of fault picking and horizon picking carried out on the seismic cross section with crossline 10241 are shown in Figure 2 below. Based on Figure 2, there are several fault points that intersect around the seismic trace and lines that extend based on the top marker used.

Time Structure Map

The time structure map was created based on the interpretation results of horizon picking in the BRF, TAF, and SB-10 formations. The time structure map was created with the

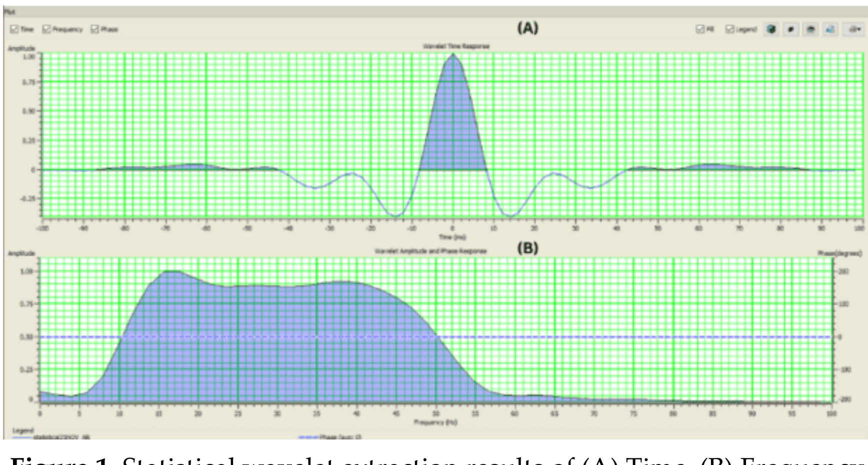

Figure 1. Statistical wavelet extraction results of (A) Time, (B) Frequency

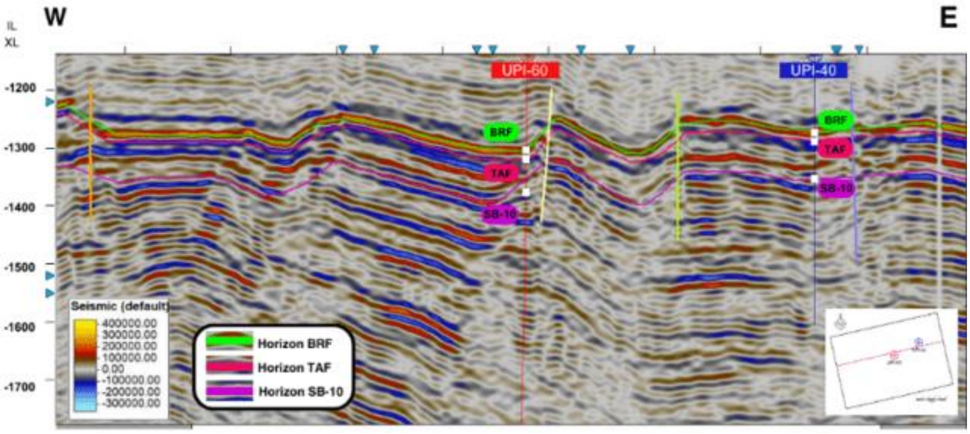

Figure 2. Picking fault and picking horizon on crossline cross section

aim of understanding the subsurface structure of the research area in the time domain (ms). The time structure map of the BRF layer is shown in Figure 3, which is the result of the interpretation of the time structure map of the BRF formation, showing the presence of a fault marked with a pink line that is on a plane parallel from the west to the east of the surface. The fault is characterized by a fairly large change in the survey time value. The elevation time in yellow to red with a value range of around -1260 ms to -1160 ms is an area with a high elevation value, while for the elevation time marked with green to purple with a value range of -1280 ms to -1460 ms is an area with a low elevation value.

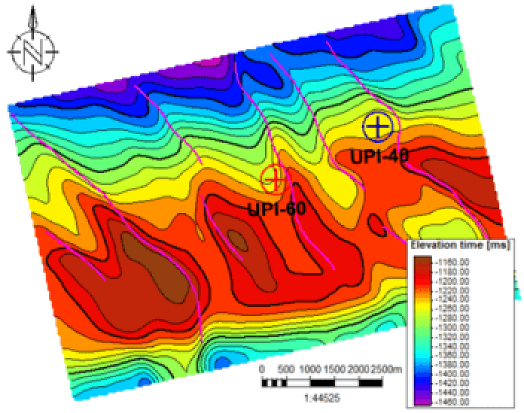

Figure 3. Time structure map of the Baturaja Formation

Envelope Attribute Analysis

Based on the results of the application of attributes using the envelope attribute, the surface attribute is predicted to accumulate hydrocarbons in several brightly colored points around the seismic cross section. The following is the result of the application of the envelope attribute to the seismic cross section of the Afara field of the Baturaja formation. Figure 4 is the result of the application of the envelope attribute to the Baturaja formation of the Afara field. This hydrocarbon is able to absorb energy originating from seismic waves, resulting in high amplitude values. Based on the image above, the area with a high amplitude value is shown in the brightly colored area (bright-spot), it is estimated that there is an accumulation of hydrocarbon reservoirs in areas that have a value range of around 280,000 ms to 440,000 ms around the UPI-40 well. Meanwhile, in the UPI-60 well, there is no bright-spot point which is estimated that there is no hydrocarbon accumulation in the well.

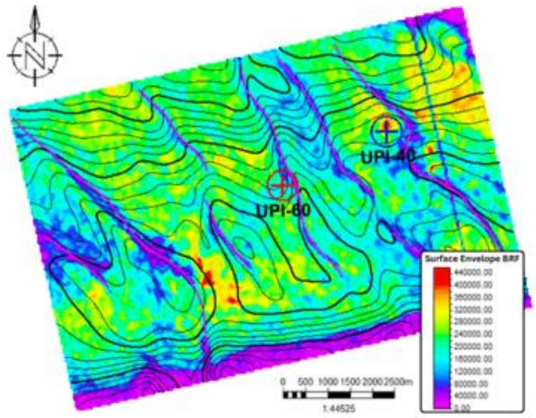

Figure 4. Surface attribute envelope of the Baturaja Formation

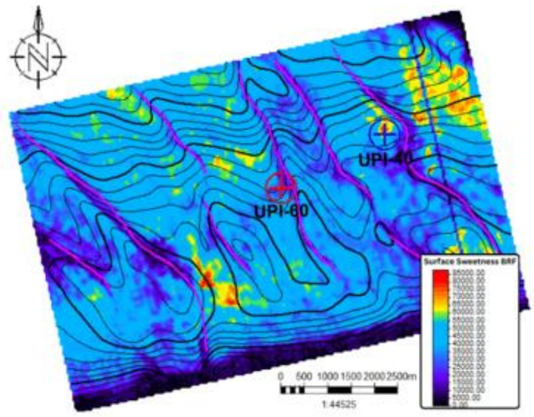

Figure 5. Slicing cross-section of sweetness attributes in the Baturaja Formation

Sweetness Attribute Analysis

The application of the sweetness attribute is carried out to identify the sweet spot area that indicates the presence of hydrocarbons in reflectors that have high amplitude values and low frequencies. Figure 5 shows the results of the application of the sweetness attribute on the seismic cross section of the Afara field of the Baturaja formation. The results of the application of the sweetness attribute on the Baturaja formation show that there is a distribution of hydrocarbons in the sweet spot area marked by orange to yellow with a value range of around 60,000 to 80,000 ms around the UPI-40 well. Meanwhile, in the UPI-60 well there is no sweet spot point which is estimated to be no hydrocarbon accumulation in the well. The results of the interpretation of the sweetness attribute on the seismic cross section are the same as the results of the interpretation using the envelope attribute. This is because the sweetness attribute is the result of the division between the envelope attribute and the square root of the instantaneous frequency (Lu et al., 2016).

Ant-Tracking Attribute Analysis

The next analysis was to determine the faults present in the area surrounding the Afara field. Before applying seismic attributes, structural smoothing was applied to eliminate noise with excessively high or low amplitude values around the seismic trace. After applying structural smoothing, the variance attribute was applied, which is used to measure lateral continuity at specific amplitudes and to clarify discontinuities. The following shows the application of the ant-tracking attribute after the structural smoothing and variance attributes have been applied.

The results of applying the ant-tracking attribute to the Baturaja formation based on Figure 6 show the presence of discontinuities, indicated by high amplitude values. These discontinuities are indicated by values ranging from -0.2 to 0.6, colored black to blue, and cut vertically along the surface. Values of -1 to -0.5 indicate no discontinuity (continuity), indicated by white to gray. The volume of this attribute is used to represent faults, which can assist in the lateral fault retrieval process (Di et al., 2019).

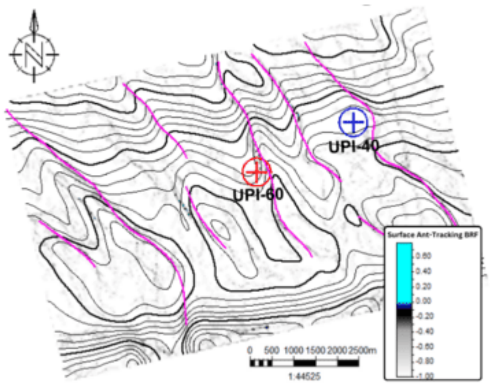

Figure 6. Slicing cross-section of ant-tracking attributes in the Baturaja Formation

CONCLUSION

Based on the research results, it can be concluded that the envelope attribute can be used to interpret the distribution of hydrocarbon reservoirs in the Baturaja Formation in the Afara Field. Several bright-spots containing high amplitude values ranging from 280,000 ms to 440,000 ms were found around the UPI-40 well. However, no bright-spots were found in the UPI-60 well, suggesting no hydrocarbon accumulation in that well.

The sweetness attribute can be used to interpret the distribution of hydrocarbon reservoirs in the Baturaja Formation in the Afara Field. Several sweet-spots containing high amplitude and low frequency values, indicated by orange to yellow, with values ranging from 60,000 to 80,000 ms were found around the UPI-40 well. However, no sweet-spots were found in the UPI-60 well, suggesting no hydrocarbon accumulation in that well. The results of the sweetness attribute analysis are similar to those obtained using the envelope attribute.

The ant-tracking attribute can be used to identify the presence of fault structures characterized by discontinuities with a value range between -0.2 to 0.6 which are black to blue in color and cut vertically on the surface.

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