

Survey of Low Frequency Passive Seismic (LFPS) Uncovers Hydrocarbon Potential in North Kalimantan Delta

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Abstract. The implementation of seismic surveys, especially in the delta region of North Kalimantan, to discover potential oil and gas reserves is not an easy task. However, there is a pressing need to enhance exploration and development activities in order to find new areas with hydrocarbon potential reservoirs. The application of the LFPS method in hydrocarbon exploration and development has begun to evolve. The prospects of this method for directly detecting the presence of hydrocarbons have yielded results and offer great hope for the world of hydrocarbon exploration and development. This survey aims to provide additional information about the distribution of hydrocarbons, while mapping passive seismic anomalies will reveal potential hydrocarbon zones in the development and exploration fields– Simenggaris Block, North Kalimantan. The results of processing passive seismic data are presented as amplitude spectrum values within the frequency range of 1-5 Hz. The amplitude values indicate the relative level of hydrocarbon potential in the area. The passive seismic attribute values obtained from the Simenggaris Block data are mapped in the form of a classed postmap to illustrate the attribute values at each point and contouring based on LFPS attribute values. Based on the LFPS attribute analysis in the South Sembakung and Tanah Merah areas, it can be identified that hydrocarbon potential is indicated by the variance in amplitude values with a cut-off value that divides the area into non-prospect, non-economic, and prospect zones.

Keywords: Amplitude, LFPS Method, North Kalimantan

1. Introduction

Passive seismic surveys for the purposes of hydrocarbon exploration and development are a relatively new approach in Indonesia, stemming from advancements in instrumentation technology originally intended for military purposes, specifically the development of ultra-high sensitivity broadband seismometers used to detect very weak acoustic signals (micro-acoustic) at extremely low frequencies (infrasonic).

Passive seismic surveys for hydrocarbon exploration are a new development in Indonesia and represent a novel method stemming from instrumentation technology originally intended for military purposes. This involves the development of ultra-high sensitivity broadband seismometers, which are used to detect very weak acoustic signals (micro-acoustic) with extremely low frequencies (infrasonic) (Suryanto et al., 2008a, 2008b).

The application of passive seismic methods in the exploration and development of hydrocarbon fields has begun to evolve. The prospects of this method for directly detecting the presence of hydrocarbons have yielded results and provide great hope for the world of hydrocarbon exploration and development. The success of this method has been demonstrated through several survey results in Pertamina's fields and has been validated for the exploration and development of oil and gas fields at Pertamina with an 78% success rate (2023).

Passive seismic survey was conducted in the development and exploration fields – Simenggaris Block. The purpose of this survey is to obtain the distribution of hydrocarbon potential through the mapping results of passive seismic anomalies, which will indicate potential hydrocarbon zones in the Simenggaris Block.

The processing of passive seismic data was conducted at 109 survey points that were acquired based on the structural prospect map. The results of the passive seismic data processing are in the form of amplitude spectrum values within the frequency range of 1-5 Hz. The amplitude values indicate the relative potential level of hydrocarbons in the area. The attributes of passive seismic data processed from the Simenggaris Block are mapped in the form of a classed post-map to illustrate the attribute values at each point and contouring based on the LFPS attribute values.

Well calibration measurements are used to find the cut-off value for LFPS anomalies at well locations where drilling results are already known. Ideally, anomaly calibration is performed at well locations that have been proven to contain hydrocarbons and those that have been confirmed dry well across all intervals. In the LFPS survey in the Simenggaris Block, reference well measurements have been conducted in the existing area.

The cut-off value for LFPS anomalies is determined based on the amplitude values at wells that have been confirmed not to contain hydrocarbons as non-prospect areas and wells that have been confirmed to contain hydrocarbons as prospect areas. For this Simenggaris Block, there are production, dry, and suspended wells, so the selection of reference wells is also grouped based on these three criteria.

2. Data and Methodology

The processing of passive seismic data is carried out through several stages, including the selection stage of passive seismic events that are relatively free from disturbances caused by transient events. Subsequently, the selected events are filtered using a polarization filter to determine events that tend to originate from a vertical direction (from below). More detailed information on the processing flow of passive seismic data can be seen in Figure 2.

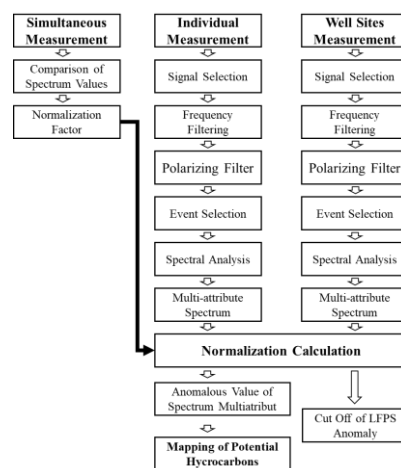


Figure 2. Data processing flow of passive seismic.

2.1. Filtering

Digital signal processing, a filter is a process used to eliminate unwanted data or signals, which are referred to as noise. In this context, the method used to remove or reduce the noise present in the signal involves eliminating certain unwanted frequencies.

Filtering is performed with the aim of eliminating noise from the expected stationary signal. For noise with frequencies higher than the target frequency (>4 Hz), which is generally caused by human activity on the surface, frequency filtering can detect such noise.

In some measurement cases, surface-originating noise can persist for extended periods or occur repeatedly, thus not being observed as a transient signal with a duration shorter than the data recording duration, but rather resembling a continuous signal with a long duration. Examples of such noise include activity on busy highways, continuous vibrations from factory machinery, and activities related to nodding wells, among others. Noise recorded from these sources can significantly affect, even dominate, passive seismic data recordings. Noise sources with frequencies within the target frequency range of this passive seismic method can also influence the results of multi-attribute calculations, particularly frequency attributes. Polarization analysis is used to detect such noise.

2.2. Automatic Event Selection

Passive seismic methods, earthquake events are considered noise rather than the target objects. These earthquake events must be selected beforehand to avoid being processed in subsequent passive seismic processing. In addition to earthquake events, other local noises apart from stationary signals also need to be eliminated. The process of detecting seismic events can be carried out using various methods.

- a. Waveform substraction

The waveform subtraction method is a technique for detecting seismic events by subtracting the amplitude value from the amplitude value of the previous sample. Mathematically, the waveform subtraction method is formulated by the waveform subtraction equation for automatic event detection:

$$k_i = d_i - d_{i-1} \quad (1)$$

$$l_i = l_{i-1} + \frac{k_i - l_{i-1}}{10} \quad (2)$$

$$m_i = m_{i-1} + \frac{l_i - m_{i-1}}{250} \quad (3)$$

Where, m_i is the signal resulting from the waveform subtraction calculation at sample- i and d_i is the original signal at sample- i .

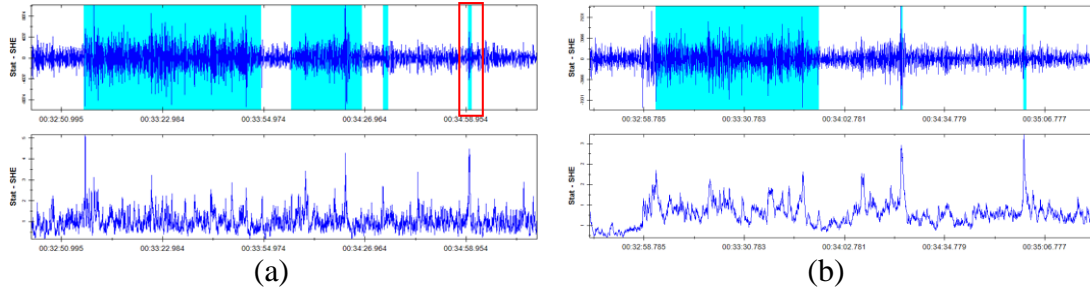


Figure 3. Example signal with a sample rate of 100 Hz (a) and 20 Hz (b) that has undergone event detection calculations using the waveform subtraction method, with light blue blocks indicating areas estimated as seismic events (top). Results of the event detection calculations (bottom).

b. STA/LTA

The STA/LTA method is a technique that calculates the ratio between the Short-Term Average (STA) and the Long-Term Average (LTA). Mathematically, the STA/LTA calculation is formulated as follows:

$$STA = \frac{\sum_{j=i}^{i+l_1} d_j^2}{l_1} \quad (4)$$

$$LTA = \frac{\sum_{j=i}^{i+l_2} d_j^2}{l_2} \quad (5)$$

$$r_i = \frac{STA_i}{LTA_i} \quad (6)$$

Where, STA is Short Term Average, LTA is Long Term Average, d_i is sample- i data and r_i is ratio STA and LTA at sample- i .

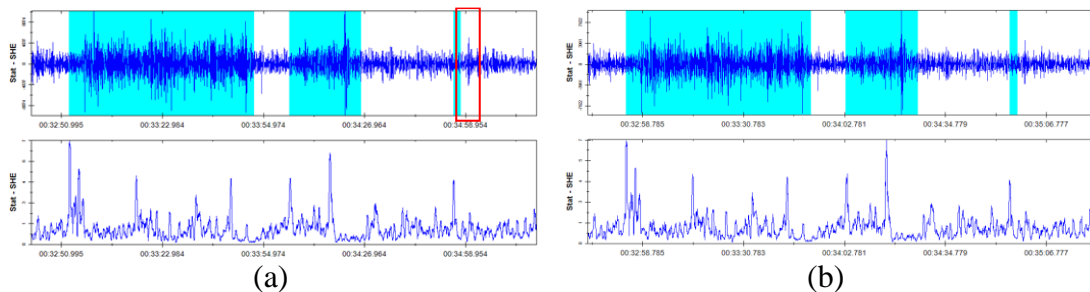


Figure 4. Example signal with a sample rate of 100 Hz (a) and 200 Hz (b) that has undergone event detection calculations using the STA/LTA method, with light blue blocks indicating areas estimated as seismic events (top). Results of the event detection calculations (bottom).

2.3. Polarization

The purpose of polarization analysis is to select signals originating from below the Earth's surface (anomaly signals) and to discard signals coming from near the surface (noise). To achieve this, it is

necessary to calculate the dip angle and rectilinearity for all data before further data processing is conducted.

Signals with a high dip angle ($>80^\circ$) are considered to originate from anomaly sources, while signals with a low dip angle ($<80^\circ$) are regarded as surface noise. The process of calculating and selecting signals with high dip angles is performed automatically, making it very fast. The rectilinearity value indicates the quality of the signal's polarization. A linearly polarized signal has a rectilinearity value of 1, while a circularly polarized signal has a rectilinearity of 0. In this survey, signals with a rectilinearity greater than 0.7 are selected.

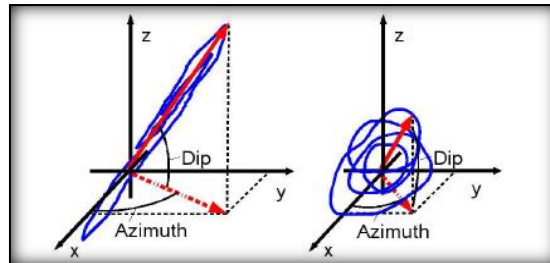


Figure 5. Signal polarization indicates the difference in dip angle and rectilinearity values. The azimuth angle represents the direction of incoming micro seismic signals in the horizontal plane, while the dip angle indicates the direction of incoming signals in the vertical plane. The rectilinearity value reflects how accurately these directions are determined; the closer the value is to 1, the better the determination of the azimuth and dip directions.

2.4. Spectral Multiattribute

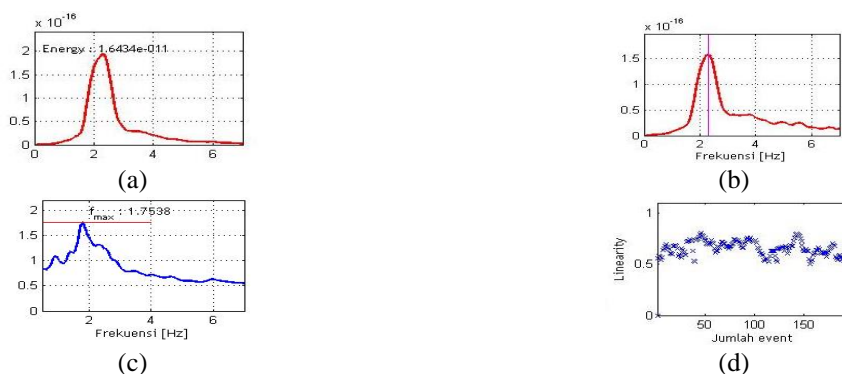


Figure 6. (a) Attribute is the energy spectrum, calculated based on the area covered by the amplitude spectrum line (mean value), (b) Attribute is the amplitude spectrum value. This amplitude spectrum value is proportional to the hydrocarbon potential in the area. The higher the amplitude spectrum value, the greater the hydrocarbon potential. The red line represents the mean value of the amplitude spectrum. This mean value is recorded as the value representing the amplitude spectrum at the observation point. (c-d) Passive seismic attribute is the VHSR (Vertical to Horizontal Spectral Ratio). This attribute is useful for assessing data quality based on the recorded noise (figure 6.c). In figure 6.d, a rectilinearity value greater than 0.6 is shown to ensure that each processed signal segment originates from below the surface, as it is well polarized vertically.

3. Results and Discussion

The results of passive seismic data processing are in the form of amplitude and energy spectrum values within the frequency range of 1-5 Hz. The amplitude and energy values indicate the potential level of hydrocarbons in the area. The cut-off value for LFPS anomalies is determined based on the amplitude values from wells that have been confirmed to contain no hydrocarbons and those that do contain hydrocarbons. However, in this area, the indicator for the presence of hydrocarbons is the production well, while the indicators for the absence of hydrocarbons are the suspended wells and dry wells.



Figure 7. Histogram of the amplitude (a), energy (b), frequency (c) and VHSR (d) spectrum attribute in the LFPS of development and exploration areas – Simenggaris Block.

Based on the analysis of passive seismic attributes in the development and exploration area of Simenggaris Block, hydrocarbon potential is indicated by higher amplitude spectrum values. It can be identified that hydrocarbon potential is demonstrated by the amplitude spectrum values of LFPS with cutoff values from well-b dry well (Amplitude value 5) for non-prospect conditions, and well-d suspended well (Amplitude value 16) for non-economic conditions, as well as well-c production well (Amplitude value 21) for hydrocarbon potential conditions (Figure 8).

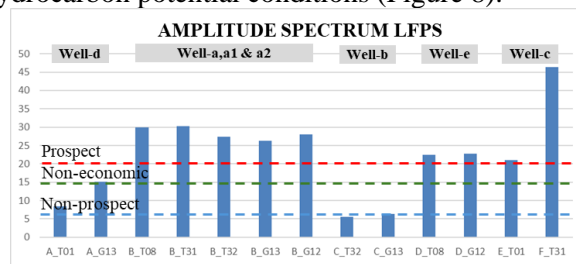


Figure 8. Amplitude spectrum attribute values in the LFPS of development area and cut-off amplitude values based on reference wells.

The potential hydrocarbon areas of development and exploration can be identified based on the amplitude values of the LFPS spectrum, indicated by yellow and red colors after applying a cutoff based on the reference well amplitude values. The hydrocarbon prospect zones for development and exploration in the Simenggaris Block are shown by the contours of the LFPS spectrum amplitude attribute values above the reference well cutoff of well-b suspended well (amplitude value 5) (Figure 9) and well-d dry well (amplitude value 16) (Figure 9). Meanwhile, the contours of the LFPS spectrum amplitude attribute values above the reference well cutoff for well-c production well (amplitude value 21) are presented in Figure 9.

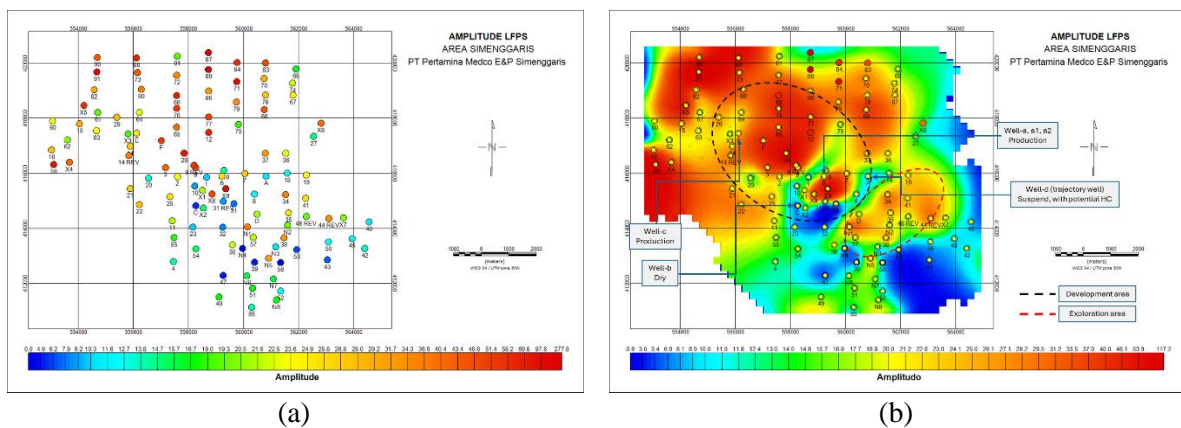


Figure 9. (a) The amplitude attribute values and (b) Map of the amplitude spectrum attribute in the LFPS area of development and exploration.

4. Conclusions

Based on the analysis of passive seismic attributes at the well site in the development and exploration areas – Simenggaris Block, it can be identified that the hydrocarbon potential is indicated by the LFPS spectrum amplitude (A) values with a cutoff:

| | | |
|--------------|------------|--------------|
| Value A > 5 | Dry | non-prospect |
| Value A > 16 | Suspended | non-economic |
| Value A > 21 | Production | prospect |

On the amplitude distribution map, it is shown that hydrocarbon potential is indicated by the LFPS spectrum amplitude values in yellow and red.

Acknowledgments

The author would like to express sincere gratitude to Mrs. Neni Herawati, the Manager of the Technical Planning Department at JOB Pertamina-Medco E&P Simenggaris, the PHE Upstream Innovation team, Mr. Edin Akhmad Syaripudin and Mr. Fanny Rosdiawan for their assistance in developing exploration and development prospects in the Simenggaris Block.

References

- [1] Dangel, S., M. E. Schaepman, E. P. Stoll, R. Carniel, O. Barzandji, E. D. Rode, and J. M. Singer, 2003, Phenomenology of tremor-like signals observed over hydrocarbon reservoirs: *Journal of Volcanology and Geothermal Research*, 135–158.
- [2] Graf, R., S.M. Schmalholz, Y. Podladchikov, and E.H. Saenger, 2007. Passive low frequency spectral analysis: *Exploring a new field in geophysics: World Oil*, 228, 47-52.
- [3] Holzner, R., P. Eschle, H. Zuercher, M. Lambert, R. Graf, S. Dangel, and P. F. Meier, 2007, *Applying microtremor analysis to identify hydrocarbon reservoirs: First Break*, 23, 41–49.
- [4] Jurkevics, A., 1988, Polarization analysis of three-component array data: *Bulletin of the Seismological Society of America*, 78, 1725–1743.
- [5] Saenger E.H., A Torres, S. Rentsch, M. Lambert, S M. Schmalholz, Mendez-Hernandez, 2007. A hydrocarbon micro-tremor survey over a gas field: *Identification of seismic attributes*, SEG San Antonio Fall Meeting, 2007.
- [6] Suryanto, W., and Wahyudi, 2008a., Monitoring Mikroseismik untuk Deteksi Langsung Keberadaan Hidrokarbon (Micro-seismic for Hydrocarbon Detection and Identification, MHDI Tech), *Proceeding PIT HAGI 33*, 2008.
- [7] Suryanto, W., and Wahyudi, 2008b., Monitoring Mikroseismik untuk Deteksi Langsung Keberadaan Hidrokarbon, Luncheon Talk HAGI (Invited Speaker), Hotel Sahid Jakarta, Dipublikasikan dalam Majalah Resonansi HAGI Edisi 8, 2008.