An integrated approach using microtremor data for field development and reservoir monitoring: an example from Betung Field, Jambi

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Abstract. Reservoir monitoring is one of the most important aspects in oil and gas field management, because it provides industries with the required data in hydrocarbon optimization. This is often carried out in Indonesia by the TAC Pertamina-Pusako Betung Muaro Senami Jambi (PBMSJ), an organization responsible for the management and coordination of oil well activities. In 2012, the organization conducted passive seismic data acquisition and series of drilling campaigns, which successfully increased oil production in Betung Block from 43 to 652 bopd. This campaign was successfully carried out through one and two wells in 2013 and 2014, respectively. Furthermore, the pre-2017 interpretation describes the Betung Anticline as a relatively symmetrical and low angle N-S trending field, which defies the South Sumatra Basin Northwest-Southeast regional trend. This anticline, bound by two high angle normal faults, is unable to define the LKO/OWC position, leading to the consideration of a more integral interpretation approach by the PBMSJ team in early 2017. The procedure was conducted through the use of a 2d seismic line bounded with new wells and SRTM imagery, to combine subsurface structural data with the surface fundamental analogue. In 2017, a passive seismic study was repeatedly conducted in the Betung field, with only 30 measuring points. The urgency in identifying the reservoir is essential within the petroleum industry, in order to produce sufficient hydrocarbons. It is also essential in confirming the potential uses of microseismic data in storage decision-making, through a dataset acquired in Betung, based on reservoir management.

1. Introduction
Betung Field is located on the western part of the Jambi area, approximately 11 km southwest and 10 km southeast of the Bajubang and Meruo Senami Provinces, respectively. This field covers an area of approximately 5 km², which presently has 222 wells (Figure 1). The data obtained from the field is also very limited because, the entire old wells and records were abandoned and destroyed by NIAM, before the Japanese invasion during World War II. The Betung field signature product is light crude, as specific gravity ranges from 41-52 API.

The data consist of well formation tops based on logs, and two 2d seismic lines crossing the Betung field. Based on the use of a well-adjusted two-dimensional seismic interpretation, the structural map required further development of several areas, while also stating that the anticlinal structure in the southern area should be considered as an interesting prospect. However, there are insufficient data
around the drilling location, due to the occurrence of several uncertainties. In addition, the anticline is a result obtained from the two-dimensional seismic interpretation, without any control of closely available surrounding well tops.

![Figure 1. Location of Betung field.](image)

Based on this stage, the creation of an additional approach to minimize uncertainties and drilling risk was considered. A low-frequency seismic analysis was also introduced to complement the previous exhausting geological interpretation.

The significant increase in oil production is further based on the evaluation and interpretation of passive seismic application, whose measurements emphasize very low magnitude character of natural tremors amplitude and frequencies ranging from 0.2–100 Hz. When this wave propagates impinge the surface of oil and gas-bearing in sand reservoirs, they resonance both in frequencies and amplitudes. Although in the stage of research, the frequency-related anomaly occurs within the range of 1–6 Hz, which are also confirmed in some areas of measurement.

The pre-2017 interpretation indicates that the Betung Anticline is asymmetrical and low angle N-S trending field bound by two high angle normal faults, as shown in Figure 2. This interpretation is unable to define the LKO/OWC position, and has failed to explain the level of passive seismic anomalies in the Betung Field (Figure 4a and 4b).

![Figure 2. The evolution of Betung structural interpretation on a) POD original from Royal Dutch Shell, b) Inhouse POD 2011, and c) 2014 interpretation.](image)
Based on the further development of the Betung Field, the PBMSJ team attempted to enhance the current interpretation in early 2017. They created a more integral approach of utilizing SRTM imagery and 2D seismic lines bound with new wells, in order to combine subsurface structural data with a surface fundamental analogy. Presently, the only parameters that PBMSJ utilizes are only three 2D seismic lines (line no.105, no. 173, and 09JS-001) with 13 sets of well log suites.

The result of a more careful seismic interpretation yields a more complex depth structure map, which consists of a new NW-SE anticline bounded with seven faults. This map delivers the alignment of the Betung anticline to NW-SE inversion, which is conformed with the transposition phase of the South Sumatra Basin, as shown in Figure 3.

![Figure 3](image)

**Figure 3.** Seismic interpretation on a) Pre-2017 interpretation of 2d seismic line no.173, b) Post-2017 interpretation of 2d seismic line no.173, and c) 2017 horizon and fault interpretation in 09JS-001.

The previous interpretation stated that the Betung Anticline was a symmetrical and low angle N-S trending field, which also heightens the uncertainty of passive seismic data not related to the localization of anomalies (Figure 4a and 4b). However, the new interpretation is considered to have the ability in explaining the presence of a small anticlinorium complex that contains two NW-SE trending anticlines. These anticlines are symmetrical with low angle flanks, and bound by series of NW-SE faults. The trends of NW-SE normal and NE-SW cross faults further separate the west and south flanks from the main part of the field, respectively (Figure 4c). With more faults, orientation, and inter-fault relationship being interpreted, switched, and honored, the curiosity of a higher producing southern part of Betung Field was successfully explained. In addition, the unknown cause of passive anomalies in the southern part was previously explained by the presence of two anticlines that are symmetrical with low angle flank, and bound by series of NW-SE faults.

Furthermore, the passive seismic data acquisition was conducted with 60 and 30 points measurement station in 2012 and 2017, respectively. The data processing stage is based on mainly separating signal
and noise, as the interpretation of processed information with vertical N-S and horizontal E-W components successfully increases the oil production in Betung Block. The evaluation result of amplitude anomalies from the ratio of vertical to horizontal magnitude within 1-6 Hz, indicates the location of trapped hydrocarbon irrespective of the depth.

The new interpretation also provides a clearer relationship between the structural and stratigraphical elements of southern Betung, as shown in Figure 4. Hydrocarbon occurrences within the southern part of the field further contributes to minimizing the drilling risk. Although the basic concept of passive seismic analysis and interpretation was still debatable, this technology was successfully applied in Betung. In addition, further methodology approaches of passive seismic and other supporting data are still needed to delineate the oil-bearing reservoirs.

Figure 4. Comparison of Betung structural interpretation with passive seismic anomalies on a) pre-2017 structural interpretation, b) Pre-2017 structural interpretation overlaid with passive seismic anomalies, c) Post-2017 structural interpretation, and d) Post-2017 structural interpretation overlaid with passive seismic anomalies.
Reservoir monitoring is one of the most important elements in oil and gas field management, due to providing industry experts with the required data to maximize hydrocarbon recovery. A comprehensive technology of this process should be capable of recording changes in reservoir fluid saturations, measuring previous and present locations of displaced fluid fronts, as well as subsequently predicting methods by which these fluids are distributed in the future [1].

The identification of the capacity or distribution of the reservoir to produce hydrocarbon, especially oil, is important in the petroleum industry. This involves understanding the drainage radius or level (distance from the borehole) of oil extraction from the reservoir. Therefore, the role of the bubble map in describing the oil drain radius is very important. In addition, this new interpretation approach is also responsible for the reduction of drilling risk.

This study aims to enhance the understanding of reservoir monitoring, and to obtain the hydrocarbon prospect area in Betung, especially strengthening the probability of occurrences within the southern part of the field. An anomalous low frequency is utilized in order to understand the linearity between passive seismic data within 2012 and 2017, which is supported by geological data and a bubble map.

2. Problem Formulation
Based on the field development, reservoir monitoring, and utilization of passive seismic survey results (acquired in two different years), is this study eligible to provide an overview of storage distribution? Furthermore, the passive seismic surveys conducted twice in 2012 and 2017 serves as time-lapse monitoring, in order to describe the radius of hydrocarbon drainage or reservoir behaviour in the Betung structure.

3. Data and Method
Low frequencies were considered to be a noise in conventional seismic analysis, due to surface sources, including human activities, as well as atmospheric and water phenomena. However, the anomaly within low frequencies was hypothetically concluded as a hydrocarbon occurrence in passive seismic analysis. In contrast to the conventional active seismic, this method was carried out with continuous and passive (without any man-made sources) measures on signal or background noise above the earth surface. The measurements involving the use of passive seismic above the hydrocarbon reservoir also provided a response with the occurrence of spectrum attribute anomaly, at the frequency range of 1-6 Hz. Meanwhile, these anomalies were not shown in other locations outside the reservoir [2]. In addition, there were several theories and hypotheses related to the source of spectrum attribute anomaly in the low-frequency range. One of these principles was the interaction between the micro-wave and hydrocarbon within the reservoir pore, which emitted the new signal at the frequency range of 1-6 Hz [3].

![Figure 5. Natural seismic sources detected in passive seismic survey [2].](image-url)
The anomaly of V/H (vertical to horizontal) and vertical spectrum ratios systematically correlated with the hydrocarbon occurrence, after the measurements on the points above the reservoir. The anomaly and amplitude peak in V/H was between the frequencies of 1-6 Hz [4] and 2-3 Hz [5], respectively. The equation used to obtain the ratio of V/H is [4],

\[
\frac{V}{H} = \frac{V(f)}{H(f)} = \frac{V(f)}{\sqrt{X^2(f) + Y^2(f)}}
\]

V/H Spectrum Ratio Attribute Equation. Where V(f) = Vertical component spectrum, H(f) = Horizontal component spectrum, X(f) = Horizontal component spectrum east-west, Y(f) = horizontal component spectrum north-south.

Furthermore, general workflow began with data acquisition, processing, and interpretation. Based on using three-component portable seismometer (X, Y, and Z), this acquisition process accomplished 60 and 30 stations in 2012 and 2017, respectively (Figure 6), near the wells and unexplored area. Each station also had measurement durations of approximately 70 mins.

**Figure 6.** Basemap with two lines of 2d seismic (black lines). Purple dots are 2012 measurement stations and blue dots are the 2017 measurement stations.

The processing stage was performed to eliminate unwanted signals and noises, as well as change domain from time to frequency. After this, data objective was to improve the signal to noise ratio on the spectrum attribute. Based on the measurement results, quite a few noises were obtained, although they originated far away from human activity. However, there were several analytical stations located near the river or trees. To obtain a noise-free signal, backgrounds with strong disturbances at several intervals should be cut down.

The use of various spectrum attributes to identify the anomaly was further carried out, in order to interpret and analyze the low frequency passive seismic data. Furthermore, the vertical to horizontal (V/H) spectrum ratio was focused on, due to having better stability than other attributes, when
measurement is conducted at different time intervals [7]. To obtain this exact range of frequency spectrum anomaly in 1-6 Hz, the spectrum attribute at the measurement area near the oil-producing well was used. This range (1-6 Hz) served as a variation with high amplitude anomaly, which often occurred in the hydrocarbon reservoir zone.

![Figure 7. Signal response above reservoir and outside reservoir in frequency spectrum[6].](image)

Based on the anomalies obtained, the passive seismic result was assumed to assist in monitoring the reservoir and plans for field development (location of the development well). Although the basic concept of passive seismic analysis and interpretation was still debatable, this technology was successfully applied in Betung. In maintaining continuity, it was necessary to monitor the production behaviour of reservoirs and wells, which were greatly influenced by the movement and presence of hydrocarbons below the surface.

Reservoir monitoring in the Betung field was also carried out by observing the results of passive seismic in two different years, with the distribution of the anomaly expected to be in line with oil drainage from each well, and illustrated through the bubble map. The results were combined in the form of a map, with that of the passive seismic anomaly distribution. These combinations further became an illustration of hydrocarbon distribution in the Betung area, based on providing additional data to determine the layout plan of the drilling well and production surveillance.

4. Results and Discussion

Based on the first passive seismic in 2012, the calibration of three wells was carried out, with each location having a different production history and vertical to horizontal (V/H) spectrum ratio. According to well 198 (oil and water producer) and 204 (suspension with 100% water production), the peak V/H values were 0.52 and 0.31 at 2.15 and 3.2 Hz, respectively. Meanwhile, the EL-BTH point that was further drilled in 2013 had a peak V/H value of 0.99 at 3.22 Hz, as well as the initial oil production of 126 BOPD and 0% water cut.

In 2017, a passive seismic study was repeatedly conducted in the Betung field, although only 30 measuring points were utilized. This was because production and development scenarios focused on the southern area of the Betung field (90% of the total production). In addition, the calibration was carried out at the same point as that of 2012. Based on Figure 8, the results of the amplitude spectrum were similar to the range of 1-4 Hz, at the CG-A and TT-BT points carried out in 2012 and 2017, respectively.
Figure 8. Passive seismic calibration in 2012 (left) and passive seismic calibration in 2017 (right).

Figure 9. Comparison of passive seismic anomalies map on a) 2012 and b) 2017 results.

Although the map results from the passive seismic did not directly show the position of the hydrocarbon or non-hydrocarbon fluid, they provided an overview of the V/H spectrum ratio distribution. Based on the map obtained in 2017, there were more widespread changes in the anomalies, when compared to the results of 2012. This was due to drilling and production activities in the southern area, where passive seismic described hydrocarbon anomalies or presence. To reservoir monitoring, the result was combined with the bubble map of the drainage radius or the cumulative oil production.

Based on limited data in the Betung field, the calculation of the oil drainage radius was carried out by using the volumetric method. This method considered the reservoir to be a tube and conducted calculation by using its volume with the cumulative production and storage properties. From this calculation, the reservoir was depicted in the form of a bubble map, which was expected to provide an
overview of the oil amount in the area, although the shape of the drainage was not ideal as a sphere. This was due to the heterogeneity of the reservoir.

**Table 1.** Cumulative production and oil drainage radius.

| Well      | Cumulative Production (mbbl) | Volumetric Oil Drainage Radius (m) |
|-----------|------------------------------|-----------------------------------|
| BTJ-209   | 350                          | 124                               |
| BTJ-210   | 429                          | 159                               |
| BTJ-211   | 615                          | 215                               |
| BTJ-213   | 254                          | 130                               |
| BTJ-214   | 107                          | 67                                |

The wells with the bubble map of the drainage radius only produced oil, except the BTJ-214 that contained water. The well with the largest drainage radius in the Betung field was BTJ-211, which historically had a great result rate, since its initial production of 164 BOPD with zero water cut on July 2014.

![Passive seismic 2017 (left) and passive seismic 2017 results overlaid with oil drainage radius bubble map (right).](image)

According to the integration data from 2012 and 2017, the structural reinterpretation, production monitoring, and anomaly distribution of passive seismic was linear with the oil drainage radius in the southern area wells. This was because the ability of the new method had the ability to estimate the presence of hydrocarbon fluid extraction, which was described as the cumulative production in each well. Furthermore, monitoring used a map of the oil drainage radius obtained from the calculation of cumulative production, reservoir properties, and recovery factor. The description of the bubble map also provided an approach in monitoring reservoir behaviour, which in this case was the oil drainage pattern.

Based on the combination of the passive seismic method and oil drain distribution, reservoir monitoring was influenced by several factors, including the utilized production technique, pump adjustment, and good storage management. These were carried out by regularly observing the fluid level, in order not to damage the reservoir.
5. Conclusion
The calibration stage was very important, in order to avoid the production of error or misinterpretation during data processing. This stage was carried out at three points in 2012, and was further repeated at the same location in 2017. The role of well data was also very important, as the interpretation and processing of G&G information was used to validate the results of passive seismic. This was carried out to determine the occurrence of trapped hydrocarbons with high vertical to horizontal (V/H) spectrum ratio.

The study indicated that there was a strong relationship between the distribution of anomalies and size of hydrocarbon drainage radius on the production field. Therefore, a time-lapse of oil drainage should be obtained in a certain area, with the ability to corroborate this data to field development, in terms of well replacement.

This study supported the microtremor or passive seismic signals theory, which provided a glimpse presence of hydrocarbon and its movement. Therefore, additional data from G&G and reservoir studies are needed, in order to strengthen the results of the passive seismic method.

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