Hydrocarbon Prospect Derived from Attributes Analysis on Low-Frequency Passive Seismic Survey: a Case Study from Kalimantan, Indonesia

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Abstract. Hydrocarbon Microtremor Analysis is a low-frequency passive seismic method which derives a quick look estimates new hydrocarbon reservoir prospect area. This method based on the empirical study which investigated an increasing of spectra anomaly between 2 – 4 Hz above the reservoir. We determined five attributes on low-frequency band of microtremors including Power Spectral Density integral of vertical component (PSD-IZ), Power Spectral Density (PSD) on 3 Hz frequency, frequency shifting, the spectral ratio of vertical and horizontal components (V/H) maximum and integral of spectral ratio of vertical and horizontal components (V/H). We deployed 105 points of measurement spreading in our suspect area. We used time series data that recorded from particle velocity of three components with 80 minutes duration and 100 Hz of the sampling frequency. The noise identification analysis in each station data set has been made from the measurement location, considering the suspect area had different local cultural noise. We proceed attributes for each data acquired from all station then used the interpolated map using a standard kriging algorithm spatially. As a result, each attribute analysis and spatial attribute map are combined to identify and estimate a good prospect of the hydrocarbon reservoir.

1. Introduction
Recent studies of low-frequency passive seismic survey or called Direct Hydrocarbon Indicator (DHI) in the range of frequency of 2-6 Hz indicates that the frequency content of the seismic background noise changes over the reservoir of hydrocarbons [2, 3, 5, 10]. Analysis of spectrum amplitude of the passive seismic data accumulated from reservoir hydrocarbon shows anomaly spectrum at a frequency of approximately 1-5 Hz with signal peaks around 3 Hz as observed in the oil fields of Abu Dhabi [5, 2], Brazil Mossoro field and field Voitsdorf Austria [6]. Furthermore, [10] give some good results about hydrocarbon reservoir related passive seismic attributes maps with the well drilled after the passive seismic survey, confirmed hydrocarbon prospect in the exploration area maps.
Based on that experience, the passive seismic survey was conducted over the green area located onshore in the Central Kalimantan. We deployed 105 points of measurement spreading with grid about 1 km node spacing in our suspect area approximately 400 km$^2$ using four station seismometers. We used time series data that recorded from particle velocity of three components with 80 minutes duration and 100 Hz of the sampling frequency. The noise identification analysis in each station data set has been made from the measurement location, considering the suspect area had different local cultural noise.

2. Methodology

Signal processing was used to calculate the passive seismic microtremors data raw taken from three components seismometer. We choose 1 minutes of time windowing which sampled the data with good signal to noise ratio by using STA/LTA algorithm. These data selection resulted into a component in every station. For every window, we calculated Fast Fourier Transform (FFT) spectra and a smoothing moving average of 30 data were applied to derived spectrum anomaly from each station.

Dangel et al. [3] suggested the primary goal identify low-frequency energy anomalies that expected with hydrocarbon reservoir-related microtremor (i.e., approximately 1-6 Hz) could be determined by attribute related to the strength of spectral peaks [10]. In this study, we determined five spectral attributes on the low-frequency band of microtremors including:

2.1. Power Spectral Density integral of vertical component (PSD-IZ)
The integral value under the power spectral density curve of the vertical component [6]. Figure 1a illustrated the integration to quantify low-frequency anomalies visible in the power spectral density plot.

2.2. Power Spectral Density (PSD) on 3 Hz frequency
The peak amplitude of 3 Hz frequency vertical spectrum component (Figure 1b) [5].

2.3. Frequency Shift of Maximum Spectral Peak
Determine frequency value on maximum spectral peak (Figure 1b). In this study, we use a range of 2.3 – 3.7 Hz. [3, 2, 10] as the DHI indicator range.

2.4. The Spectral Ratio of Vertical and Horizontal components (V/H) maximum
This attribute represents to reduce the instability between vertical and horizontal component related to the time of measurement. The procedure is to measure the maximum of V/H ratio spectra between 1-6 Hz (Figure 1d) [6].

2.5. Integral of Spectral Ratio of Vertical and Horizontal components (V/H)
This attribute represent to reduce the instability between vertical and horizontal component related to the time of measurement. The procedure is to measure integral of V/H ratio spectra between 1-6 Hz above V/H=1 [10]. Figure 1d illustrated the integration to quantify in V/H ratio spectra plot.

Figure 1a show the 60 minutes continuous recorded waveform at station PS082, ground particle velocity (m/s) versus sample number of 100 Hz sampling frequency for three components, Up-Down (Vertical U-D) (above), north-south (horizontal N-S) (middle) and east-west (horizontal E-W). Green color are indicates set of a time window which was used for further processing for each component to get the amplitude spectrum analysis. Furthermore, smooth amplitude spectrum of three component, black line represent up-down (vertical U-D), red line represent east-west (E-W horizontal) and blue line represents north-south (N-S horizontal) component (Figure 1b). Blue area is quantified an anomaly of the power spectral density of the vertical component in the low-frequency (approximately between 1.7 and 3.7 Hz), value of PSD-IZ (blue area) attribute is 421.3545 arbitrary units, the amplitude spectrum value on frequency 3 Hz (PSD 3Hz) is 266.3544 (red dash line), and frequency
shifting in 2.5 Hz (Figure 1c). Blue area is a quantifies an anomaly of the spectral ratio V/H attribute (approximately between 1 – 6 Hz), the value of integral V/H ratio spectra is 1.7779 arbitrary unit, with maximal peak 1.5 (Figure 1d).

**Figure 1.** Spectral attributes of the microtremor waveform used in this study (from measurement PS082, as an example). (a) Raw data 3 component (b) Smooth spectrum of 3 components (c) Smooth amplitude spectrum of the vertical component and the Power Spectral Density of the vertical component (PSD-IZ) attribute (d) The spectral ratio V/H (Vertical/Horizontal) attribute.

### 3. Results and Discussion
This processing procedure is applied to the all passive seismic data of each measurement stations points. As an output, all spectral attribute maps were generated base on a specific attribute. Attributes values were mapped spatially about the station location (Figure 2). Combined standard kriging interpolated algorithm attribute map shows slicing area which derived new hydrocarbon reservoir prospect (orange area). Red line represent PSD-IZ attribute values, thick red line represents cut off values more than 100; Green line represent PSD-3Hz attribute values, thick green line represent cut off values more than 100; Blue line represent contour map frequency shifting attribute values, with thick line represents value 2.3 – 3.7; Magenta line represent contour map of spectral ratio V/H attribute which thick line represent value more than 1; Purple line represent contour map integral of spectral ratio V/H attribute which thick line represent value more than 0.6. Green point represent interesting new hydrocarbon reservoir prospect; yellow point represent middle interesting and red point represent not interesting, based on statistically score and value combined.

This comes into our consideration that the DHI range of spectrum attribute values needs to be adapted from noise effect near survey site or any other seismic source. The adaptation can be made by considering noise identification and controlling the DHI range using calculated attribute values from known hydrocarbon production stations [4, 8, 1, 7], that aspect can increase or decrease the amplitude and frequency of hydrocarbon microtremors.
4. Conclusions
Based on our study, we can summarize DHI range for 5 attribute value mention before as follows: PSD IZ: >100; PSD 3Hz: >100; Frequency Shift: 2.3-3.7 Hz; Integral V/H: > 0.6; and V/H Maximum: >1. Each attribute analysis and spatial attribute map are combined to identify and estimated a good prospect of a hydrocarbon reservoir. We derived that orange area (Figure 2) is the most prospective hydrocarbon area, based on five spectral attributes and to be suggested for the exploration well placement.

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