RESEARCH ARTICLE

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Earthquake Broadband-Noises Experiments: Spectrogram and Spectral Analysis for Hydrocarbon Reservoir Detection

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The aim of this study is to improve understanding of the subsurface hydrocarbon reservoir detection using low-frequency passive-filtered seismic broadband-noises experiments generated by earthquake that occurred in the region of South Sumatra on July 13, 2010. The experiments utilized three components of the earthquake broadband-noises data, which were obtained from eight seismic stations located around oil fields in the South Sumatra Province, Indonesia. The data were then examined using spectrogram and spectral analysis to better understand the characteristics and origin of hydrocarbon micro-tremors induced by the noises. The results indicated that before and after the earthquake micro-tremor signals normalized amplitudes on spectrograms and the peaks of the signals were in good agreement with detected locations of hydrocarbon reservoirs.

Keywords: Earthquake Broadband-Noises, Spectogram, Spectral Analysis, Hydrocarbon Reservoir.

1. INTRODUCTION

We are interested in examining broadband-noises for detection of a hydrocarbon reservoir using spectrogram and spectral data analyses because the novel method of hydrocarbon reservoir detection is required for petroleum industry. Such a method is well-known as passive-filtered seismic spectral analysis.[1] In this method, the spectrum of passively acquired micro-tremors is measured using three component of earthquake broadband-noises experiments for amplitude anomalies within the ranges of earthquake broadband frequencies, usually from 1 to 10 Hz.

Noise recorded by a seismometer is likely influenced by various possible sources that affect frequency band of earthquake signals. Noises with frequencies below 1 Hz are mostly generated by sea waves whereas those with frequencies above 1 Hz are caused by traffics in urban areas.[2] The noises generated by sources having frequencies below 1 Hz allow us to better understand the interaction of the solid earth, oceans, and atmosphere.

Other noises with frequencies of 1–6 Hz known as micro-tremors can provide a low-cost solution to mining exploration that does not damage in urban areas, where geo technical information is often difficult to obtain.[3] Consequently, measurements of micro-tremors have been used in many studies to determine the speed, the thickness of shallow sediments and the fundamental resonant frequency.[4,5]

Micro-tremor amplitude anomalies of the spectrum signals in the range 1–6 Hz, with a peak of about 3 Hz, have been observed and reported by a number of studies working on hydrocarbon reservoir detection.[6–8] These studies found that there is a strong correlation between detected micro-tremors spectral amplitude anomaly and the presence of hydrocarbon reservoir in several oil fields. Further, the findings also indicated that the micro-tremors anomaly was not found at all locations classified as non-hydrocarbon reservoirs.

Previous work on this issue suggested that analysis of hydrocarbon micro-tremors can be used to determine exploration potential and production of hydrocarbons.

Micro-tremor analysis can also be used to monitor the border area of exploration for placement optimization and drilling risk reduction.[9–11] In another study a strongly linear correlation between the observed tremor signals and the thickness of a hydrocarbon layer was confirmed and found in various oil fields.[12]

In this study, we performed spectrogram and spectral analysis to characterize the field records of earthquake broadband-noises and present the corresponding results of three components of the broadband-noises experiments carried out over oilfields around South Sumatra Basin. The main aims of this research were thus to examine the characteristics of micro-tremor signals and to determine whether the signals could be used as indicators for hydrocarbon reservoirs.

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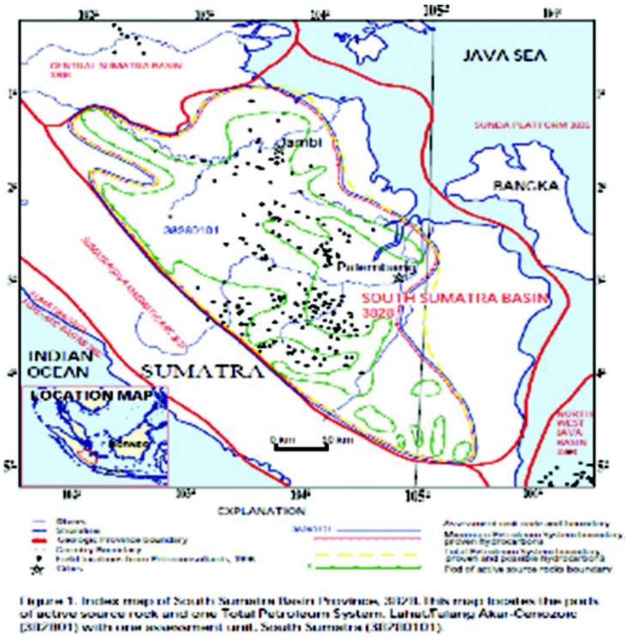

Fig. 1. Oilfields where experiments were performed in south Sumatra province.

2. GEOLOGICAL SETTING

The oilfields where the experiments were performed are located at the South Sumatera Province as shown in Figure 1.

South Sumatera Basin in the province was formed by three-phase processes of large plate tectonics: Firstly, in late Paleocene to early Miocene formed grabens north-trend filled with Eocene to early Miocene deposits. Secondly, normal fault tranquility of the early Miocene to early Pliocene. Thirdly, the existence of the involvement of compression, basin inversion, and reversal of normal faults in the Pliocene to the formation of anticlines which is a big trap in the area. Rift basin is situated above an unconformity in a variety of pre-tertiary rocks.[13]

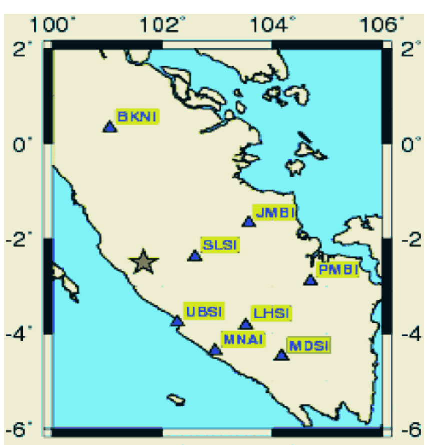

Fig. 2. Earthquake occurred in south Sumatera province on July 13, 2010 with the epicenter indicated by red star and distribution of the eight seismic stations as blue triangles providing the three-components of seismic broadband-noises used in this research.

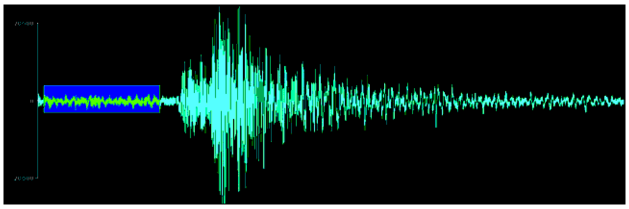

Fig. 3. The Z-component of broadband-noises (indicated by highlight blue) as recorded by JMBI seismic station before the quake occurred in south Sumatera province on July 13, 2010.

3. METHODS

3.1. Data

The data for this research are in the form of three components of broadband seismic waveforms, obtained from regions around the basin, as illustrated in Figure 1 and can be accessed at http://202.90.198.100/webdc3/.

3.2. Data Processing

The signals of broadband-noises were recorded using three components of broadband seismic stations: MDSI, MNAI, LHSI, UBSI, SLSI, PMBI, JMBI, and BKNI, as shown in Figure 2. Combined time-frequency analyses were performed to characterize the recorded earthquake broadband-noises before (Fig. 3) and after (Fig. 4) *P* onset of the corresponding earthquake waveforms.

The earthquake broadband data were first processed into normalized data. A processing window of 100 s with a preset of 1 Hz BwrthHighpassfiltered (Hpbu n 2 co 1) was used to reduce data spectral leakage and time domain to normalize the noise.

Spectrogram and spectrum analysis of the broadband-noises before the earthquake occurred in South Sumatera on July 13, 2010 were performed using SeisGram2 version 7.0. Figure 5 shows spectrogram with the vertical axis is frequency (Hz) and the horizontal axis is time domain (s) while colour degradation denotes normalized amplitude. Figure 6 describes spectrum with the vertical axis is amplitude (m/s) and the horizontal axis is frequency (Hz).

A time-frequency combined method was then used to analyze spectrograms and spectra data obtained from all the earthquake broadband-noises signals. The method has been successfully applied to earthquake signal recovery at low signal-to-noise aspect ratio for some purposes, for example, accurate estimates of instantaneous frequency, hydrocarbon reservoir detection, radar and the design of time-varying filters.[14] The method used in this research is thus the short-time Fourier Transform, defined as

$$X(t, f) = \int_{-\infty}^{\infty} x(\tau)h(\tau - t)e^{-j2\pi/t}\, d\tau \qquad (1)$$

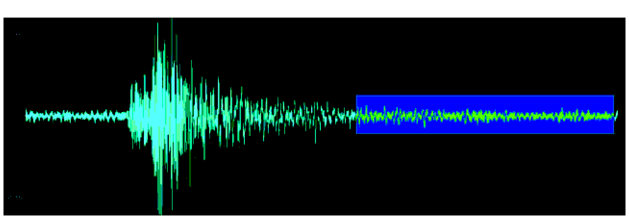

Fig. 4. The Z-component of broadband-noises (indicated by highlight blue) as recorded by JMBI seismic station after the quake occurred in south Sumatera province on July 13, 2010.

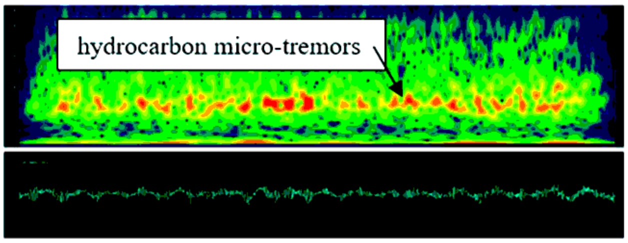

Fig. 5. Spectrogram and the Z-component of broadband-noises recorded by JMBI seismic station before the quake occurred in south Sumatera province on July 13, 2010.

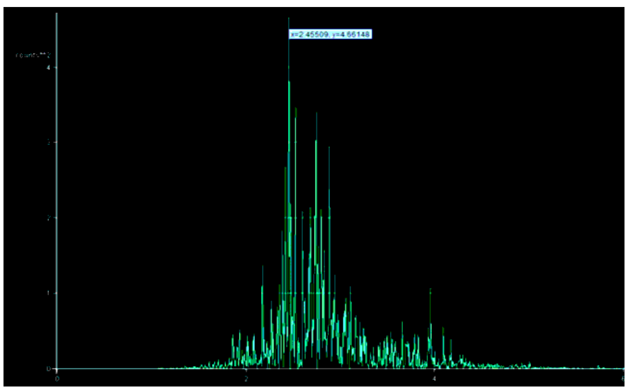

Fig. 6. The spectrum of the Z-component broadband-noises recorded by JMBI seismic station before the quake occurred in south Sumatera province on July 13, 2010, with the peak of the spectrum lying between 2 and 3 Hz.

with $x(\tau)$ denotes the broadband-noises signals considered and $h(t)$ is a window function centered at about $t = 0$. The Fourier Transform is produced by shifting the window so that it is centered at a time of interest. Then, the next step is to multiply $x(\tau)$ with the shifted production of $h(t)$ and to take the Fourier Transform of the resultant windowed signals. The windowed signals can then be shifted such that the resulting time intervals are overlapping.

4. EXPERIMENTAL RESULTS

In this section, we present the experimental results of the broadband-noises experiments using spectrogram and spectral data analysis of the corresponding seismic signals for the determination of hydrocarbon reservoir locations. Two cases considered are the broadband-noises recorded by PMBI station (Figs. 7–12) as an example of three seismic stations located above hydrocarbon reservoir (PMBI, BKNI, and JMBI) and the noises recorded by MNAI station (Figs. 13 and 14) as an example of other five stations not located above any hydrocarbon reservoir (MDSI, MNAI, LHSI, UBSI, and SLSI), respectively.

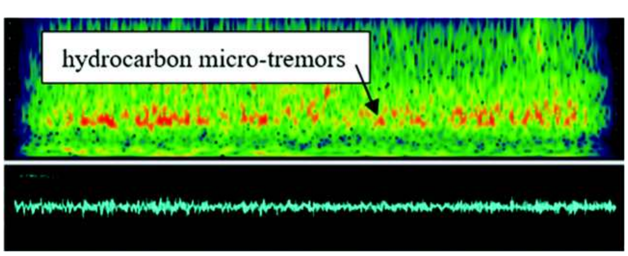

Fig. 7. Spectrogram and the Z-component of broadband-noises recorded by PMBI seismic station after the quake.

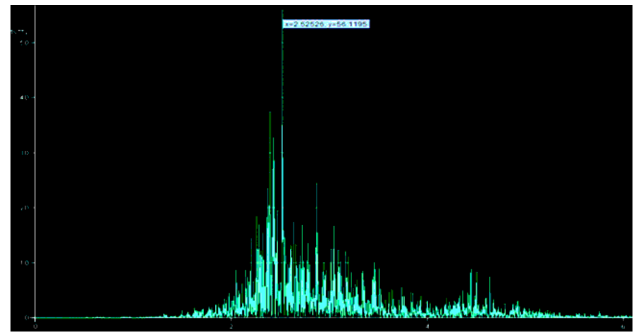

Fig. 8. The spectrum of the Z-component broadband-noises recorded by PMBI seismic station after the quake occurred in south Sumatera province on July 13, 2010, with the peak of the spectrum lying between 2 and 3 Hz.

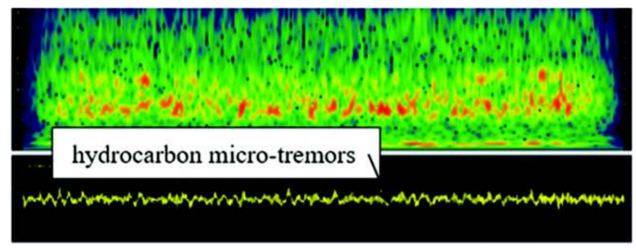

Fig. 9. Spectrogram and the N-component of broadband-noises recorded by PMBI seismic station after the quake occurred in south Sumatera province on July 13, 2010.

It is clear from Figures 7 and 8 (the vertical component), Figures 9 and 10 (the north-south component), and Figures 11 and 12 (the east-west component) that the peaks of amplitude anomalies are all lying somewhere between 2 and 3 Hz. It follows that the seismic broadband-noises are due to hydrocarbon micro-tremor signals. Similar findings are also found for the other two stations, namely BKNI and JMBI.

However, for MNAI and the other four stations, namely MDSI, LHSI, UBSI, and SLSI micro-tremors owing to hydrocarbon

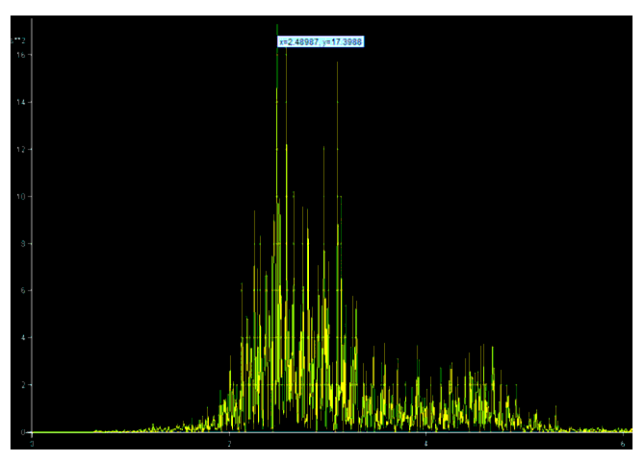

Fig. 10. The spectrum of the N-component broadband-noises recorded by PMBI seismic station after the quake occurred in south Sumatera province on July 13, 2010, with the peak of the spectrum lying between 2 and 3 Hz.

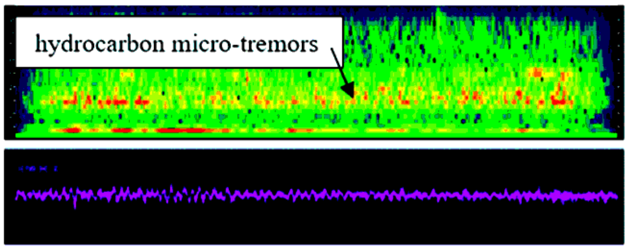

Fig. 11. Spectrogram and the E-component of broadband-noises recorded by PMBI seismic station after the quake occurred in south Sumatera province on July 13, 2010.

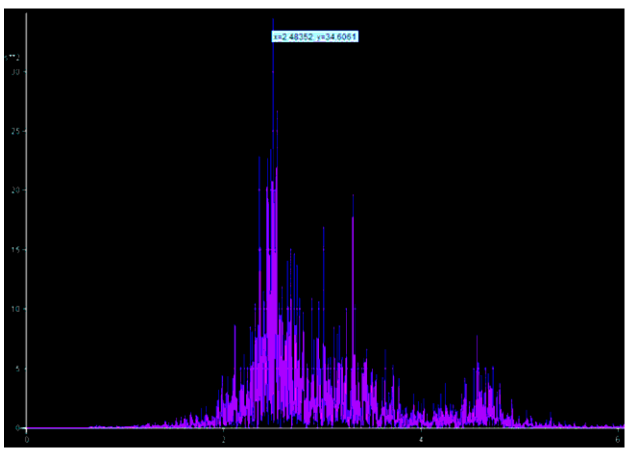

Fig. 12. The spectrum of the E-component broadband-noises recorded by PMBI seismic station after the quake occurred in south Sumatera province on July 13, 2010, with the peak of the spectrum lying between 2 and 3 Hz.

activities are not found in the areas. The following figures provide convincing arguments for undetected hydrocarbon reservoirs.

5. DISCUSSIONS

The characteristics of earthquake broadband-noises observed by eight seismic stations that are located around oilfield sin the South Sumatra Basin have been examined in relation to recent findings arguing for signals generated by micro-tremors in the range 1–6 Hz being used to detect hydrocarbon reservoir locations. The methods for use of spectrogram and spectral analysis in this study provide better argument and understanding of the nature of micro-tremor anomaly reported from hydrocarbon

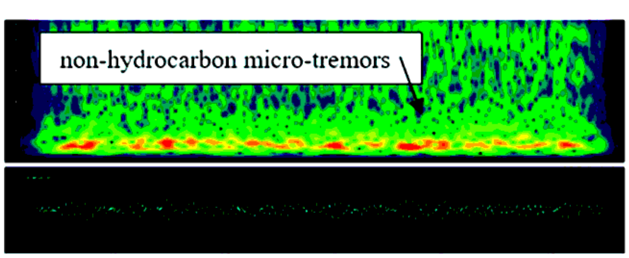

Fig. 13. Spectrogram and the Z-component of broadband-noises recorded by MNAI seismic station after the quake occurred in south Sumatera province on July 13, 2010.

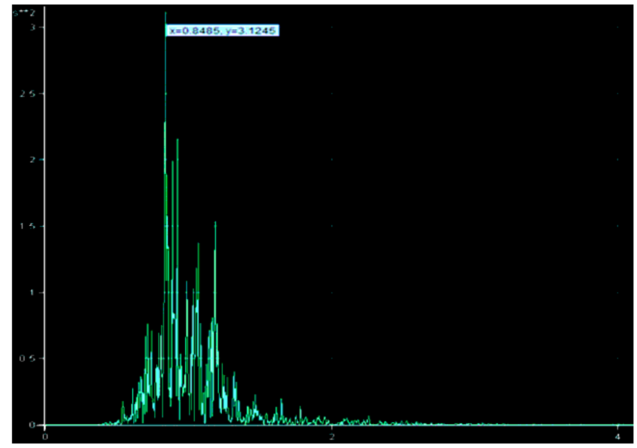

Fig. 14. The spectrum of the Z-component broadband-noises recorded by MNAI seismic station after the quake occurred in south Sumatera province on July 13, 2010, with the peak of the spectrum is less than 1 Hz.

reservoirs in the region. The results indicate high levels of amplitudes of micro-tremor signals being found by spectral analysis in the range 2–4 Hz with their corresponding peaks are distributed over a narrower frequency band of 2 to 3 Hz. Seismic stations that observed such seismic anomalies are arguably lying above hydrocarbon reservoirs, as claimed. Similar levels of the signals are also observed nearby these stations but with smaller values of frequency of less than 1 Hz associated with maximum peaks.

Considering the findings in this study, it seems that spectrograms obtained from field records of the seismic broadband-noises and the corresponding spectral analysis could effectively be used for the detection of hydrocarbon reservoirs.[15] This is in good agreement with the results of previous work,[6–8] investigating micro-tremor signals, where peak anomalies were observed in the range 1–6 Hz, with a maximum peak of 3 Hz reported. These studies, along with the research results derived from the present study, have thus argued for a strong correlation between seismic micro-tremor signals and signal-peak anomalies in spectral analysis. This correlation leads to a conclusion that in places where the anomaly is present hydrocarbon reservoir is likely to exist.[16]

6. CONCLUSIONS

Experiments on spectrogram and spectral analysis of the field data obtained from earthquake broadband-noises signals were performed. The signals were then observed as seismic micro-tremors, suggesting that low-frequencies of signal anomalies are generated by activities originating from the suspected hydrocarbon reservoirs. The results of the experiments indicate that the observed anomalies of frequency in the range 2–4 Hz with the maximum peaks at about 3 Hz are in good agreement with the presence of hydrocarbon reservoirs detected in the South Sumatra. Anomalies with peaks lying outside the range 1–6 Hz are unlikely to be good indicators for hydrocarbon reservoir detection.

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