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ASSESSMENT OF A POTENTIAL HYDROCARBON RESERVOIR IN A YOGYAKARTA BASIN USING BROADBAND-NOISE ANALYSIS

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ABSTRACT: The search for hydrocarbon reservoirs through geophysical exploration in a particular basin has been in common recently. In this study, a potential hydrocarbon reservoir situated in a Yogyakarta Basin in Central Java, Indonesia was assessed using broadband-noise spectral analysis of spectrograms recorded by 2 local seismic stations: UGM and YOGI, where the broadband data included 3 components of waveforms. The aims of this study are thus twofold; firstly, we report the characteristics of micro-tremor seismic signals generated by a hydrocarbon reservoir in the region of interest and then secondly, we examine these findings in the context of determining which seismic station is likely to be positioned above the potential reserve for hydrocarbons and estimating the depth of a hydrocarbon reservoir. The results of broadband-noise seismic experiments revealed that the peak of micro-tremor anomalies associated with a hydrocarbon reserve was only detected by YOGI station. This primary finding suggests that, instead of UGM station, the YOGI station is arguably lying above a potential hydrocarbon reservoir with the layer depth is estimated to be 12-35 m. Discussions on these results include the practical use of broadband-noise experiments with a low pass-filtered frequency in geotechnical and industrial applications.

Keywords: Potential hydrocarbon reservoir, Broadband-noise analysis

1. INTRODUCTION

Exploration activities, such as the search for oil and gas reserves using geophysical methods are common in geotechnical engineering and industrial production. In essence, any consumption of oil and gas or other forms of hydrocarbon resources must be replaced with production of oil and gas such that the net consumption and production are thus in balance. However, such exploration requires time-consuming with relatively high-cost production in the process. The field activities may involve a complex study as oil and gas reserves are deep underground and hence visually unseen.

Potential hydrocarbon reserves in Indonesia are commonly located in the back-arc basin, that is, the sedimentary basin behind the Indonesian volcanic arc. For the country, oil and gas are vital resources, playing an important role in many aspects of lives. More than 50% energy consumption in the country is in fact associated with oil and gas. This makes relatively excessive uses of these natural resources and in turn, their abundance in quantity decreases rapidly. To this end, the search for and discovery of oil and gas reservoirs in new locations are therefore crucial as Indonesian oil and gas potential reserves are large. Fossil-based or hydrocarbon energies are spread throughout Indonesian territories.

A method commonly used to detect hydrocarbon reservoirs has been an active 3D seismic method. This method is expensive and takes a long time to complete. An alternative method using broadband-noise signal analysis to detect a potential reserve of hydrocarbons with its precisely predicted location below the surface has currently been in use.

Noise signals are influenced by various sources that may affect the frequency bandwidth of seismic waves generated by an earthquake. Signals having frequencies less than 1 Hz are primarily sourced by ocean waves [1]-[2], which possibly help better understand the interaction of the solid earth, oceans, and atmosphere. Those greater than 1 Hz are usually characterized by urban traffics. Noise frequencies commonly in the range 1-6 Hz are known as seismic micro-tremors. These particular micro-tremors can then alternatively provide a low-cost solution to the problem of geophysical exploration in urban areas, where subsurface information is technically difficult to derive [3]. Hence, micro-tremor observations and the corresponding in-situ measurements have been used to determine shallow sediment thickness and fundamental resonant frequency [4]-[5].

Anomaly amplitude in micro-tremor signals in the frequency range 1-6 Hz at a peak of 2-4 Hz has been reported by previous work [6]-[7], focusing upon hydrocarbon reservoir detection. These studies claimed micro-tremor amplitude anomalies apparent in the presence of a potential hydrocarbon reservoir. As claimed, in other locations with no indication of hydrocarbon reservoirs micro-tremor signals were thus absent. It follows that the signals could possibly be a good indicator for hydrocarbon reserves.

The issue of potential hydrocarbon exploration and production finds its way through micro-tremor signal analysis. The analysis can therefore be used to determine the localized area of possible exploration for drilling optimization hence a risk reduction [8]. In another study [9], a linear relationship between hydrocarbon-induced micro-tremor signals and the thickness of a layer detected as a potential reserve for hydrocarbons was confirmed.

In the present study, we perform and analyze broadband-noise experiments on spectral analysis of micro-tremor signals using 3 components of seismic waveforms generated in a suspected hydrocarbon reservoir in a Yogyakarta basin. The main purposes of this work are twofold. Firstly, we report micro-tremor characteristics based on broadband-noise analysis in the region of interest. Secondly, we examine the report for determination of a potential location where a hydrocarbon reserve is likely to be present and an estimate of a layer depth.

2. GEOLOGICAL SETTING

Yogyakarta basin was geologically formed due to the removal of the Southern and Kulon Progo mountain at the beginning of the Pleistocene age (about 0.01-0.70 million years ago). The complex tectonic process is believed to be the age limit of Quarter in the region [10]. After the appointment of the Southern mountain, there was a puddle (lake) along the foot of the mountain to Mewarno and Baturetno. This is related to the closed surface for flow of water along the foot of the mountain so that it was then collected in the lower basin.

Merapi volcano emerged in 42,000 years ago, but andesite rocks consisting of K/Ar in Mount Bibi, as reported in [11], suggested that the activity of Mount Merapi was lasted since 0.67 million years ago. The hypothesis is that the height in the south, southwest, west, and north of Yogyakarta has thus formed a puddle along the volcano slope, separating the southern part from the Kulon Progo mountain.

In the Yogyakarta basin, volcanic activities of Mount Merapi have continually developed. Based on 14C dating and data on cinder deposits in Cepogo, the activities of Mount Merapi have been going on since ±42,000 years ago whereas the data of K/Ar field surveys obtained from lava deposits in Mount Bibi suggest that the activities have been going since 0.67 million years ago. The height to the south and the emergence of the dome of Mount Merapi to the north have formed a flat valley. The southern part of the valley is bordered by the southern mountain and the west is bordered by the Kulon Progo mountain.

In a location of a flat valley, the black clay deposits were unfolded. This clay is the boundary between the bedrock and volcanic sediment of Mount Merapi. Based on 14C dating on black clay deposits found in Progo river (Kasihan), the age of the valley is ±16,590 to 470 years, and in Opak river (Watuadeg) is 6,210 years. The black clay deposits sourced in the Opak river coincide with the sediment of Mount Merapi, leading to interpretation that the data are considered as the initial influence of material sedimentation from Mount Merapi.

The black clay deposits are also found along Winongo river (Kalibayem), which coexist with lava of 310 years-old. Thus, the volcanic activity of Mount Merapi has affected geological conditions of this area from about ±6,210 to ±310 years ago. However, soil layers of coarse materials have been encountered throughout the Yogyakarta basin.

3. METHOD

This study was conducted in a location within the Yogyakarta basin, central Java, Indonesia. The basin lies between Oya river in the eastern part and Progo river in the western part, between the active Merapi in the north and Indian Ocean in the south (Fig. 1).

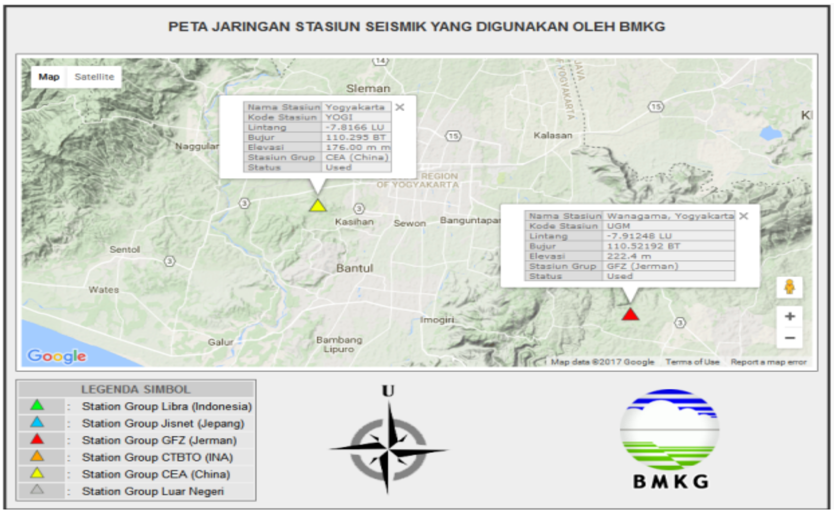

Fig. 1. Two local stations, YOGI (a yellow triangle) and UGM (a red triangle), used in this study are taken from https://inatews.bmkg.go.id/new/meta_eq.php.

The data used in this study were 3 components of broadband-noise seismic signals recorded by 2 local seismic stations: UGM at 7.91^o S and 110.52^o E and YOGI at 7.82^o S and 110.29^o E, officially operated by the IA seismic network under the supervision of Indonesian Agency for Geophysics, Climatology, and Meteorology (BMKG), Jakarta. The joint time-frequency analysis was performed to characterize the signals, which were observed starting at night from 10 pm to 5 am and during daylight from 6 am to 4 pm. The data in the form of seismic waveforms obtained from these observations (Fig. 2 and Fig. 3 as examples of the accessed data) were available at http://202.90.198.100/webdc3/.

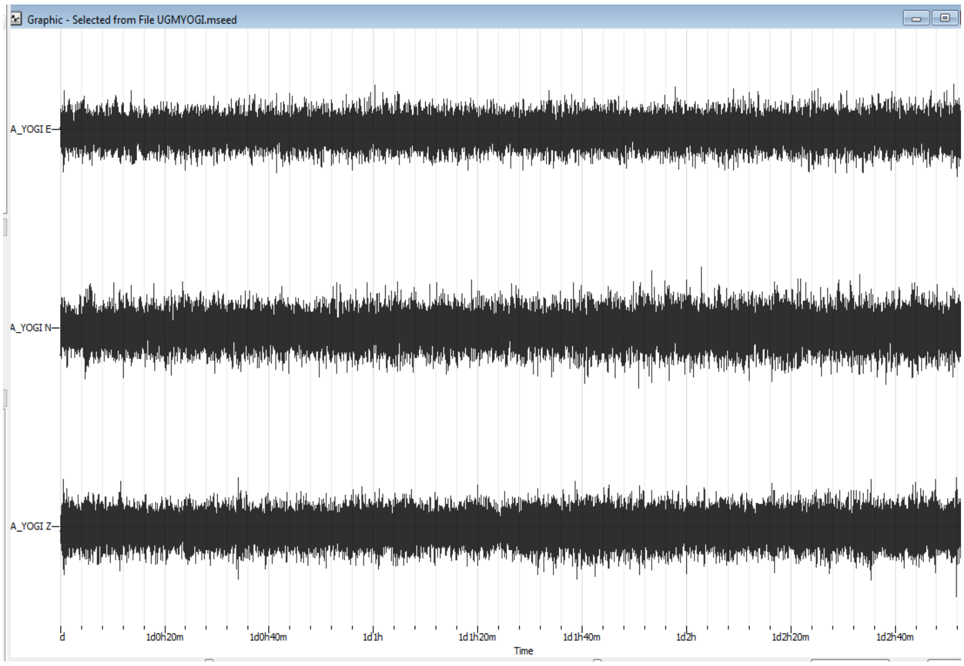

Fig. 2. Time series of 3 components (E = eastward-westward, N = northward-southward, Z = upward-downward) of broadband-noise signals recorded by YOGI station on February 19, 2017 at night from 10 pm to 5 am.

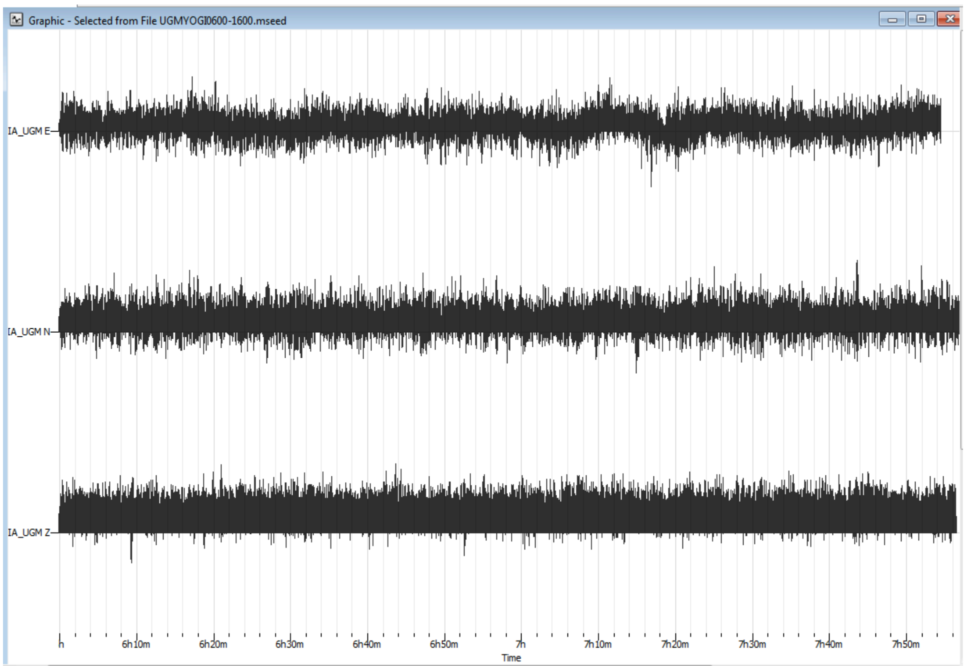

Fig. 3. Time series of 3 components (E = eastward-westward, N = northward-southward, Z = upward-downward) of broadband-noise signals recorded by UGM station on February 19, 2017 during daytime from 6 am to 4 pm.

The followings are detailed steps in the method. Firstly, the broadband-noise data were processed using a Geopsy software package to perform analyses of spectral amplitudes and correlating spectrograms. A processing window of 0.5-10 Hz was then used to reduce possible spectral leakages and time domain to normalize the 3 components of broadband-noise data. A time-frequency method was finally used to analyze spectral amplitudes of the 3 components and their corresponding spectrograms. This method has been successfully applied for a seismic wave signal recovery at a low signal-to-noise ratio for accurate estimate of an instantaneous value of frequency for hydrocarbon signals [12]. The method used in this study is the short-time Fourier transform, defined as

$$\boldsymbol{X}(\boldsymbol{t},\boldsymbol{f}) = \int_{-\infty}^{\infty} \boldsymbol{x}(\boldsymbol{\tau})\boldsymbol{h}(\boldsymbol{\tau}-\boldsymbol{t})\boldsymbol{e}^{-\boldsymbol{j2xf\tau}}\, \boldsymbol{d\tau} \qquad (1)$$

where $\boldsymbol{X}(\boldsymbol{t},\boldsymbol{f})$ is broadband-noise seismic signals and $h(t)$ is a window function centered about t = 0. The Fourier transform is produced by shifting the window so that it is centered on a time of interest, then multiplying $x(\tau)$ by the shifted production of $h(t)$, taking the Fourier transform of the resultant windowed signals. The window can thus be shifted such that the resulting time intervals are overlapping.

4. RESULTS AND DISCUSSIONS

4.1 Hydrocarbon Reservoir Detection

Detection of underground hydrocarbon reserves includes analysis of spectral amplitudes and their corresponding analysis of spectrograms for all the 3 components (Z = upward-downward direction, N = northward-southward direction, and E = eastward-westward direction) of the broadband noise signals. The following results are directly derived from both analyses, where the signals were recorded by UGM station (Fig. 4 and Fig. 5) and YOGI station (Fig. 6 and Fig. 7), respectively.

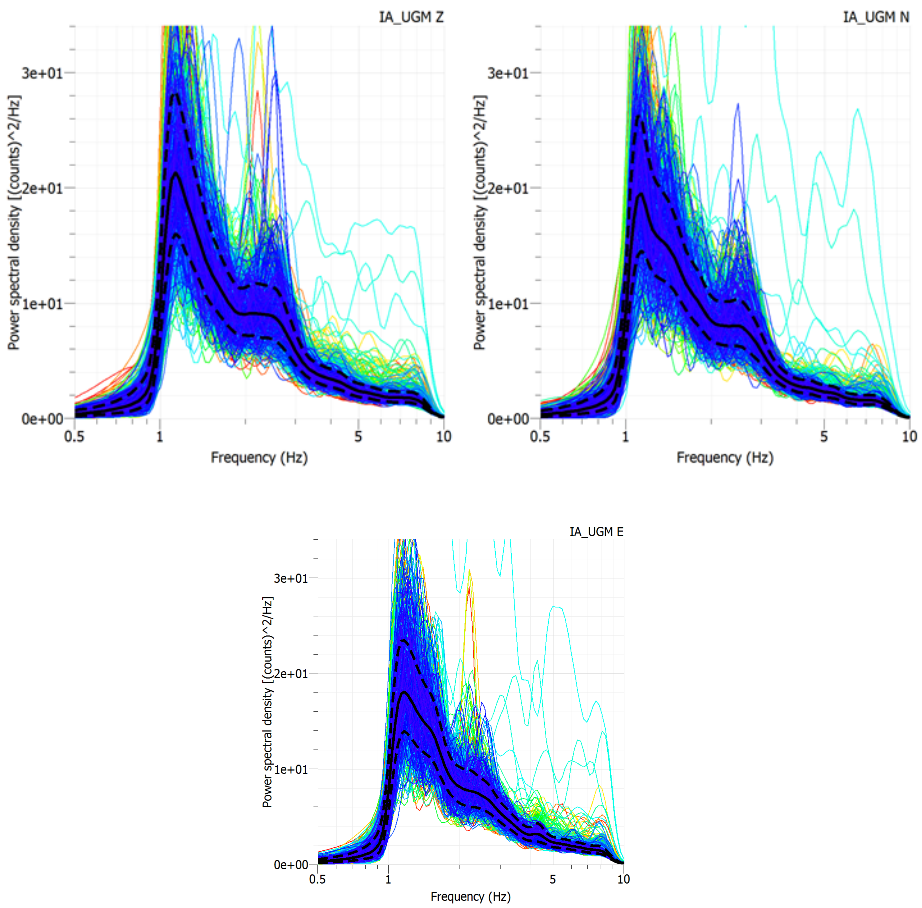

Fig. 4. Three panels of spectral amplitude analysis, showing the amplitudes of the 3 components (Z, N, E) of ambient noises with respect to the observed frequency ranges recorded by the UGM station. Many features are well understood and include microseisms in the range 0.5-10 Hz. The measured peaks of all components correspond to micro-tremor signals with frequencies of less than 2 Hz, suggesting no indication of a potential hydrocarbon reservoir above the station.

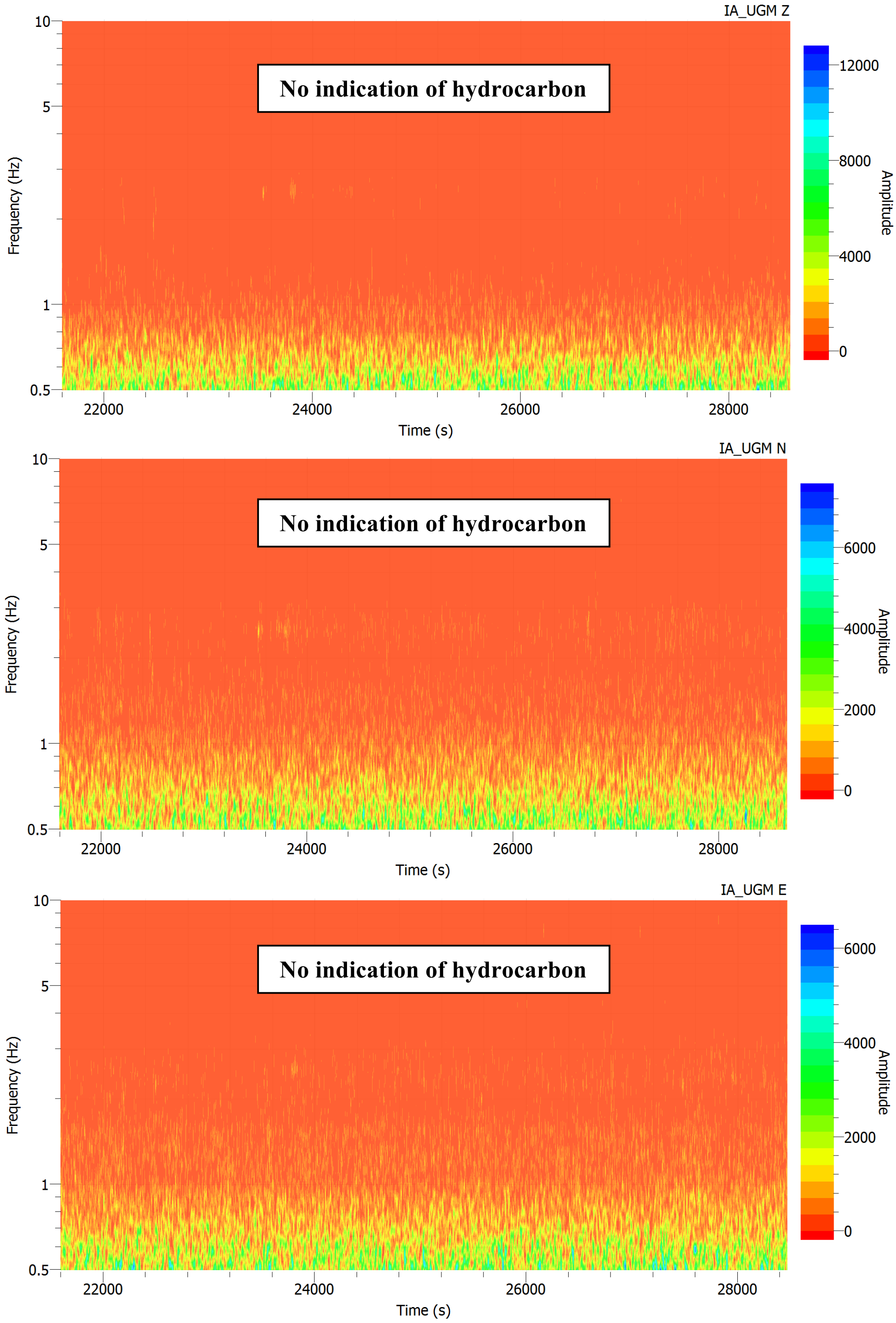

Fig. 5. Three panels of spectrogram analysis, showing spectrograms of the 3 components (Z, N, E) of ambient noises with respect to the observed frequency ranges recorded by the UGM station. Many features are well understood as micro-tremor signals of 0.5-1 Hz and possibly extended to less than 2 Hz. No signals with frequencies between 2-4 Hz indicate no potential hydrocarbon reservoir above the station.

The spectral amplitudes of the 3 components (Z, N, E) of the broadband-noises, as shown in Fig. 4, clearly do not indicate hydrocarbon reserves since the amplitudes of all components of the signals are less than 2 Hz [6]-[7]. However, for the shake of completeness this spectral amplitude analysis needs to be equipped with analysis of spectrogram, as illustrated in Fig. 5. The advantage of spectrogram analysis is due to its accuracy in detecting signals with frequency bands of 2-4 Hz in continuous times. This time-domain analysis does not trap any noise signal having frequencies between 2 Hz and 4 Hz for a particular moment of time. This analysis is a visual representation of the seismic signal presented using two axes, namely time measured in seconds as the horizontal axis and frequency measured in hertz as the vertical axis.

We also present spectral amplitudes analysis in Fig. 6 and spectrogram analysis in Fig. 7 for ambient noises observed at the YOGI station. Figure 6 shows that the power spectral densities corresponding to the signal amplitudes from all components achieve their maximum between 2 and 4 Hz (at about 3 Hz). Following [6]-[7], these features describe a possible location for a potential hydrocarbon reservoir above the YOGI local station. Figure 7 provides supporting evidence for the presence of subsurface hydrocarbon reserves as it clearly shows the signal frequencies continually recorded by the YOGI station at values of 2-4 Hz for the whole time of observations.

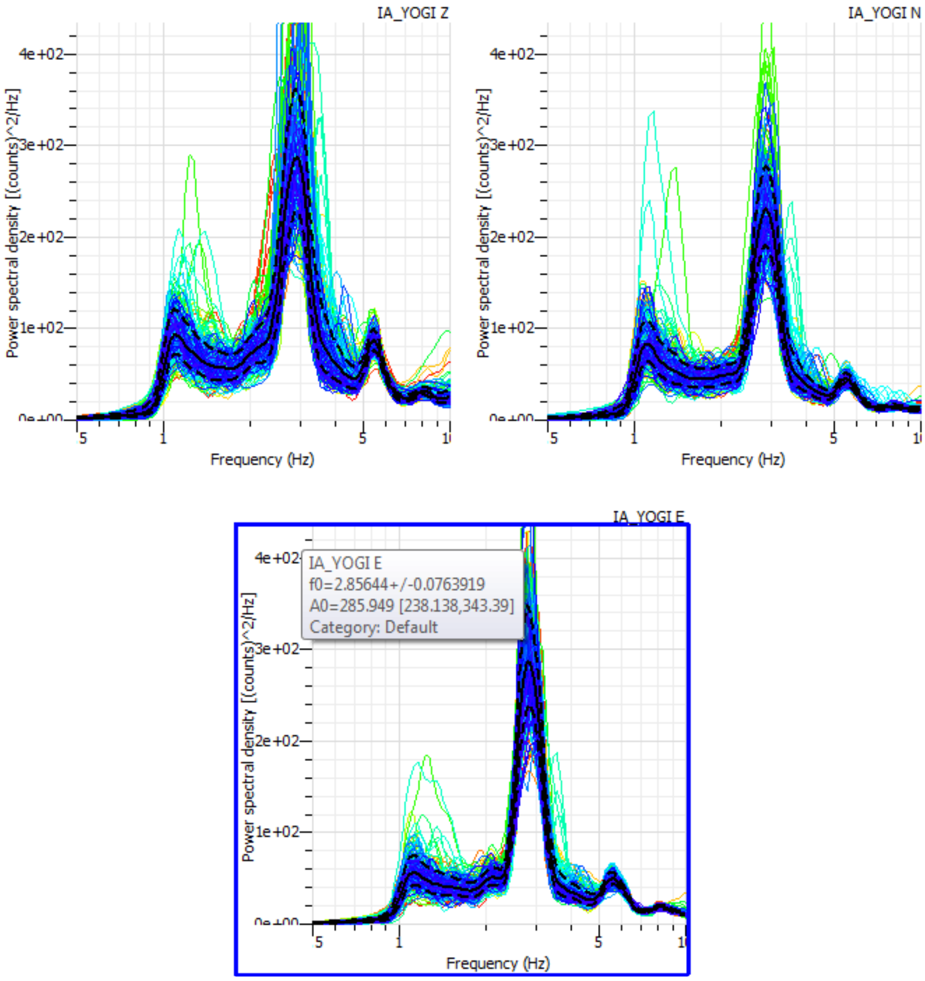

Fig. 6. Three panels of spectral amplitude analysis, showing the amplitudes of the 3 components (Z, N, E) of ambient noises with respect to the observed frequency ranges recorded by the YOGI station. Many features are well understood and include microseisms in the range 0.5-10 Hz, within which micro-tremor seismic signals of 1-6 Hz are apparently observed. The measured peaks of all components correspond to these signals with frequencies of approximately 3 Hz (see the frequency associated with the peak of power spectral density at the bottom panel), indicating a potential hydrocarbon reservoir above the station.

It should be noted here that direct comparisons between Fig. 4 and Fig. 6 extracted from the analysis of spectral amplitudes of the broadband-noise data as well as Fig. 5 and Fig. 7 derived from the analysis of spectrograms from the same signals recorded by two independent local stations (UGM and YOGI) clearly distinguish hydrocarbon-generated signals from those induced by other sources. As the peak of a signal anomaly produced by micro-tremors for all components considered is in the range 2-4 Hz for the YOGI and less than 2 Hz for the UGM, we then conclude that the possible precise location of a hydrocarbon reserve matches with a limited region deep below the YOGI station. The bottom panel of Fig. 6 also show that the corresponding frequency for the spectral peak in amplitude is achieved, illustrated inside a box in the panel, at a value of, written to two decimal places, $f_0 = 2.86 \pm 0.08$ Hz or approximate 3 Hz, lying between 2 Hz and 4 Hz as the frequencies of hydrocarbon micro-tremors.

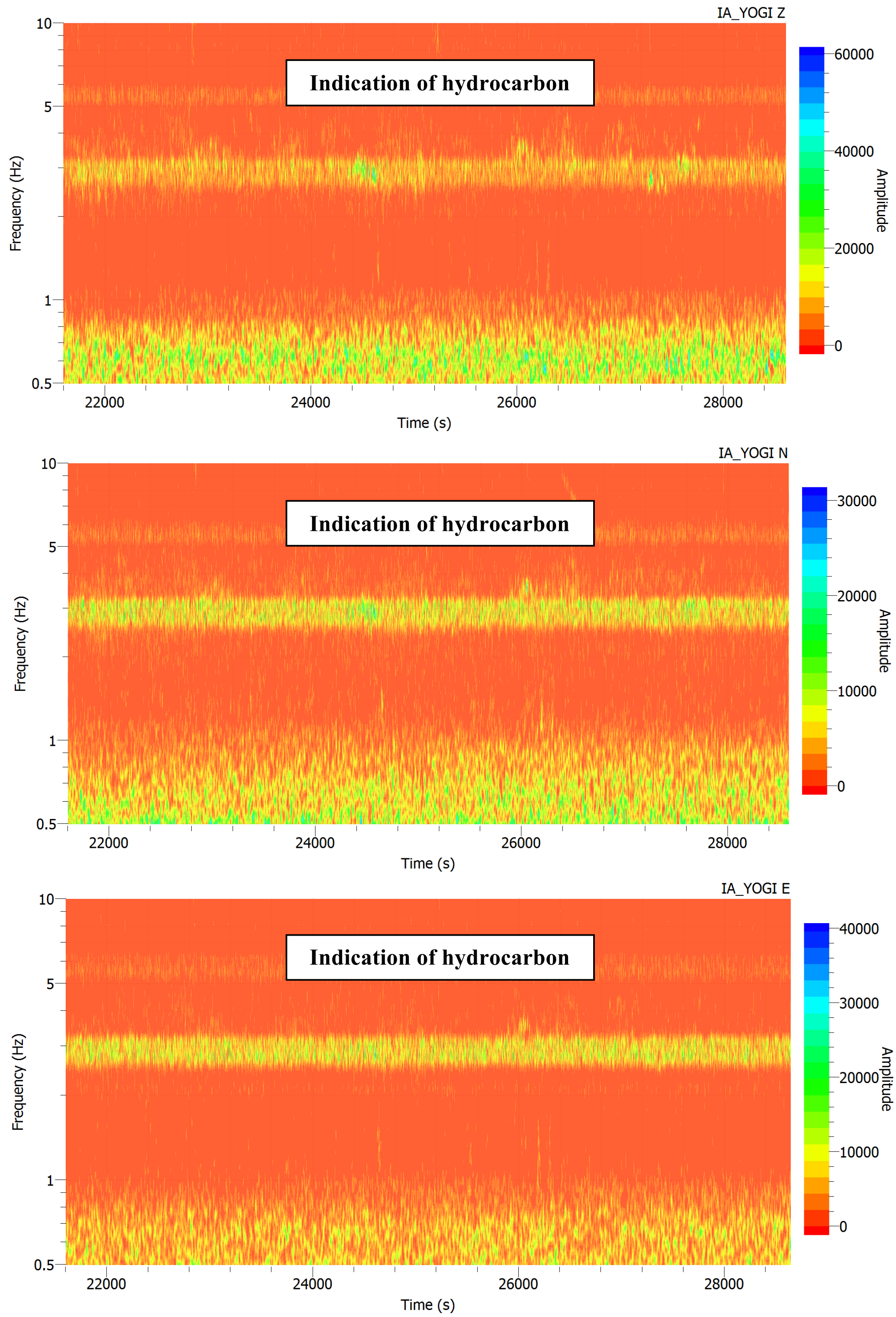

Fig. 7. Three panels of spectrogram analysis, showing spectrograms of the 3 components (Z, N, E) of ambient noises with respect to the observed frequency ranges recorded by the YOGI station. Many features are well understood as micro-tremor signals of 0.5-1 Hz and other detected signals lying between 2-4 Hz, indicating a potential hydrocarbon reservoir above the station.

4.2 Estimate of Hydrocarbon Layer Depth

For hydrocarbon micro-tremors (see the bottom panel in Fig. 6), the observed resonance frequency is estimated to be $f_0 \approx 2.9$ Hz (rounded to only one decimal place). Using this value, we then calculated the thickness of the soil hydrocarbon-layer within the Yogyakarta basin as follows,

$$f_0 = v_S/4h \quad (2)$$

where both $\boldsymbol{v_S}$ and $\boldsymbol{h}$ represent the (space and time-averaged) shear-wave velocity and the thickness of sediment deposits, respectively.

Following [9], shear-wave velocities were used from the results in and around the Kasihan region, which is nearby the YOGI station. The velocities were estimated to be in the range 140-400 m/s. Using this range of value to be inserted into Eq. (2), the thickness of unconsolidated sediments in this study was estimated to be 12-35 m. This thickness is therefore considered as the hydrocarbon layer depth.

Having analyzed the power spectral amplitudes and their corresponding spectrograms as well as estimated the hydrocarbon layer thickness, we can resolve the nature of broadband-noises recorded by local stations suspiciously situated above a potential hydrocarbon reservoir. The micro-tremor signals are lying in the range 2-4 Hz with their apparent peak anomalies measured approximately at 3 Hz, in good agreement with previous work [6]-[7]. As claimed by [9], both spectral and spectrogram analyses of broadband-noise signals can then be used to detect the possible location of a potential hydrocarbon reservoir. In particular, for the cases considered in the present work, the YOGI station is found to be likely lying above the hydrocarbon reserve.

5. CONCLUSION

We have performed and examined broadband-noise spectral analysis of micro-tremor signals using the data recorded by 2 stations nearby Yogyakarta, namely YOGI and UGM. The results reveal that the low-frequencies of anomaly signals are believed to be hydrocarbon-induced micro-tremors, originating from a location suspected to be a potential reserve for hydrocarbons. Using this argument, we conclude that the presence of a hydrocarbon reserve is likely to be below YOGI station, instead of UGM station with its resonant frequency is observed at about 3 Hz and the thickness of unconsolidated hydrocarbon sedimentation layer is in the range 12-35 m.

6. ACKNOWLEDGMENTS

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