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TIME REVERSE MODELING OF HYDROCARBON DETECTION FOR PASSIVE SEISMIC SOURCE LOCALIZATION: A CASE STUDY OF SYNTHETICS AND REAL DATA FROM THE SOUTH SUMATRA BASIN, INDONESIA

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ABSTRACT: Subsurface passive seismic source localization, which is associated with hydrocarbon indication, has become an important tool for passive seismic data modeling. A time-reverse modeling (TRM) algorithm, which was applied to passive seismic data, has been developed and implemented to locate passive seismic sources by using an acoustic finite difference technique. By performing TRM, the recorded passive seismic amplitudes can be focused at their source depth, even though the focused point cannot be warranted as a source point. This paper aims to verify the ability of the developed TRM algorithm in localizing the passive seismic source associated with reservoir depth by means the possible movement of fluid. TRM was applied to synthetic and recorded passive seismic data from a gas reservoir area in the South Sumatra Basin. Synthetic passive seismic data were generated within a two-dimensional velocity model and calculated by using a finite difference algorithm simulating acoustic low-frequency wave propagation. TRM application to the synthetic data showed that passive seismic sources can be properly located in the same position as the original source. In addition, our application to the real passive seismic data sets showed that the passive seismic source is distributed randomly in the depth range of 700 m up to 1500 m, which was represented by high particle velocities.

Keywords: Passive seismic, Finite difference, Time reverse modeling, South Sumatera basin Indonesia

1. INTRODUCTION

South Sumatra Basin is one of the greatest oil and gas producing regions in Sumatra, Indonesia. Oil production was commenced in early 1898 from the sand reservoir of the Air Benakat Formation [1]. The early discovery of the oil production was from a shallow layer close to surface seeps that were exposed within anticline structures. The Talang Akar Formation has been hypothesized as the source rock for oil generation [2], [3].

The South Sumatra Basin structurally is broken into several sub-basins that include Jambi, North Palembang, Central Palembang, and South Palembang sub-basin. Geologically this Basin is the part of Sumatra back-arc basins situated along the Sumatra province. The collision between the Eurasion plate (Sunda shield) and Indo-Australian plate caused the generation of this basin [4], [5]. Tectonically this basin was classified as an asymmetric basin, which is bounded by faults and uplifted exposures of pre-Tertiary rocks along the Barisan Mountains in the west to south direction. In the north to east direction, this basin is bounded by the sedimentary or depositional boundaries of the Sunda Shelf. The orogenic activity during the Middle Mesozoic to Plio-Pleistocene orogenic generated the current tectonic features [4]-[6].

In terms of petroleum system, the South Sumatra Basin exhibits a common postrift sequence along semi-connected NNW–SSE trending synrift basins with two main rift provinces were identified as prospective area for hydrocarbon (i.e., Jambi and Palembang). Thrust and fold trends, which is close to the active mature source rocks, was identified as a prospective oil and gas fields [1], [7]. The multiple hydrocarbon source and reservoir systems were found in the South Sumatra Basin. An exploration phase has been ongoing to develop the field. One exploration activity involves passive seismic surveys that record microtremor amplitudes.

The passive low-frequency method is a tool developed for petroleum exploration, which is intended to improve hydrocarbon reservoir detection. Spectra of low-frequency seismic events (1-10 Hz) are passively acquired by measuring microtremor signals, which are associated with the ground motion of the hydrocarbon reservoir, using three-component seismometers at the Earth's surface. A systematic low-frequency anomaly, which is acquired using a regular array of microtremor recorders on the surface over the oil and gas reservoir, has been reported by previous papers [8]-[10]. Although we are still facing the question of whether the spectral anomalies really originate from the reservoir, this approach can be empirically proven by some field experiences and more recently, a passive low-frequency seismic survey has been recommended as a technique for delineating and probing oil and gas reservoirs.

Previous experiments on the passive seismic response analysis over hydrocarbon production field show that there are correlation between low-frequency spectral anomalies and hydrocarbon reservoir [8]. The existence of hydrocarbon is indicated by dominant peak of the vertical to horizontal spectral ratio [11].

TRM, which is the reverse of forward modeling, is an algorithm used to locate the low-frequency signals (microtremors) to their originating subsurface locations. In this study, we developed and applied a TRM algorithm to identify and detect the depth of the reservoir by locating the microtremor sources from recorded microtremor amplitudes. In the current study, we applied TRM to synthetic and real passive seismic data from a related oil field in the South Sumatra Basin. Passive seismic data was simulated by using acoustic two-dimensional forward modeling of finite difference modeling. Synthetic modeling assumed that microtremors are point sources, which emit energy periodically every half second in the low-frequency interval of 1-10 Hz. The point source was numerically represented by a minimum phase wavelet. In contrast, the real low-frequency data was acquired over a gas reservoir area in the South Sumatra Basin by simultaneously recording microtremors from several seismometers.

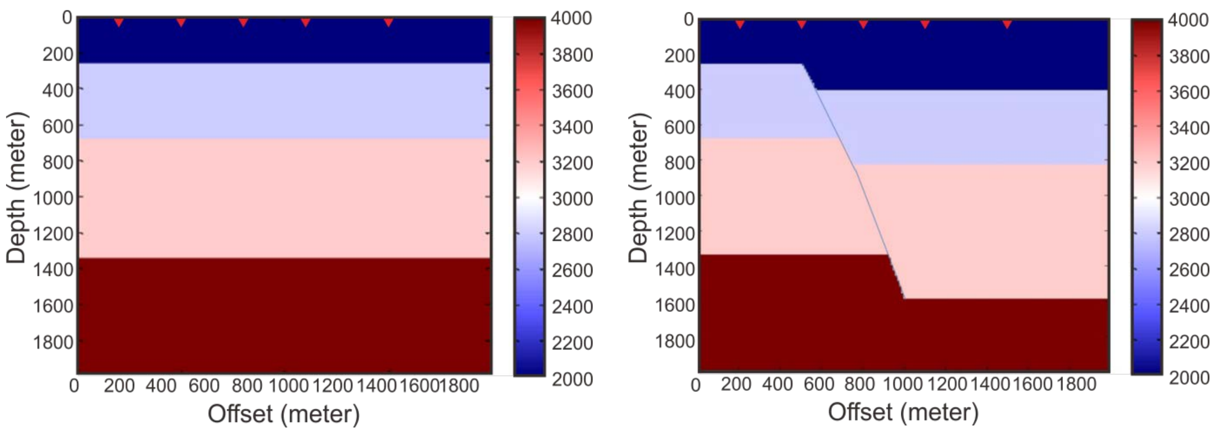
2. SYNTHETIC ACOUSTIC FINITE DIFFERENCE MODELING

Acoustic wave modeling is an important algorithm for understanding the nature of acoustic wave propagation in a medium. This modeling can be carried out using the finite difference (FD) method to estimate travel time to generate a snapshot wave field, shot record, and exploding reflector models. FD can be implemented using the order of the second and fourth approaching the scalar wave equation. A further absorption limit field can also be implemented to reduce the artificial side effects.

Numerical modeling of FD is a solution of the general wave equation, which is presented in the second derivative form the FD method (second order) of the central finite difference. Thus, we obtained a solution of the FD approach to the general wave equation as follows:

$$\varphi(x,z,t+\Delta t) = \{2+\Delta t^2 v^2(x,z)\nabla^2\}\varphi(x,z,t) - \varphi(x,z,\Delta t) \quad (1)$$

Equation (1) is an expression of the time step of the wave field. This suggests that the estimation of the wave field at the time $t+\Delta t$ requires two known initial conditions of wave field at time t and t-Δt. This mechanism is well known as time-lapsing and the wave field for every t is called a snapshot [12]. The wave field at every t was proceeded using a two dimensional (m x n) matrix.



a) b)

Fig. 1 The geometry of the two velocity models: a) simple model and b) the faulted model.

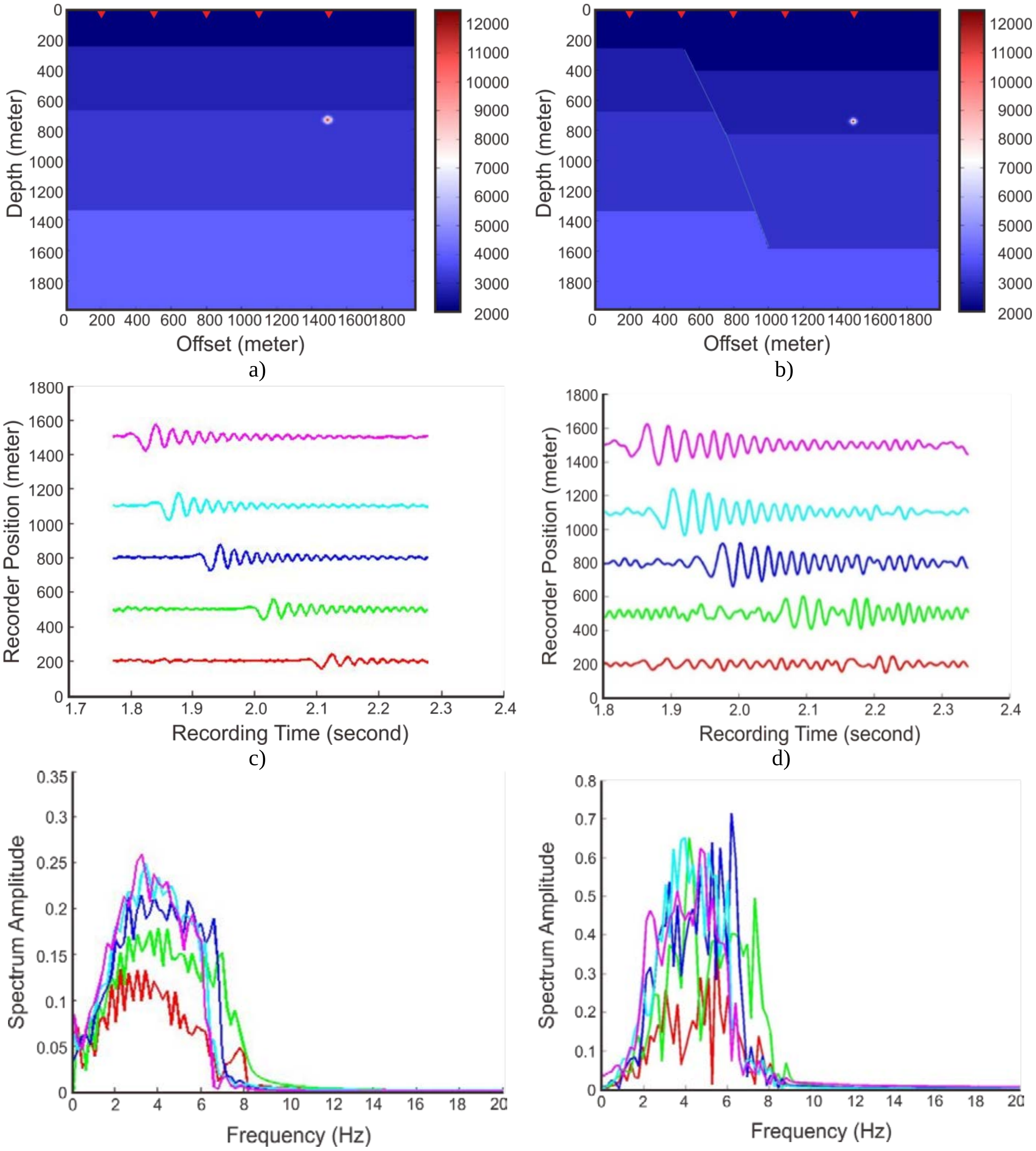


Fig. 2 The result of acoustic forward modeling based on the finite difference algorithm. Snapshot of propagation wave for a) simple model and b) faulted model. Recorded seismogram from the geometry of the two velocity models, where c) is the synthetic seismogram of the simple model and d) is the synthetic seismogram of the faulted model. The amplitude spectrum of the e) simple and f) faulted model.

In this paper, the synthetic microtremors were generated by first defining the geological model in terms of velocity model geometry, which is in the size of 200 (lateral distance) x 200 (depth) with a grid size of 10 x 10 m. The position of the seismometer was placed on the surface (depth (z) = 0 m) and at a distance of 200, 500, 800, 1100, and 1500 m. Figure 1 shows the velocity model geometry, which is illustrated with a simple a) and faulted model b). The recorded microtremors were simulated using acoustic two-dimensional forward modeling of finite difference modeling with time lapse order. The geological model was set up with a free surface for the top of the model and absorbing for the other three surfaces that representing a non-reflecting boundary [13], [14]. The initial parameters of wave propagation simulation such as time step were set up at 0.001 s, the maximum time of the seismograms was 3 s, the sources periodically emitted waves every 0.5 s, and the sampling rate was 0.004 s. The source point was located at a depth of 770 m and a distance of 1510 m, which is shown in Figure 2.

3. TIME REVERSE MODELING

The acoustic forward modeling generated continuous microtremor signals similar to natural ones, which is shown in the form of a snapshot. Figure 2a shows the snapshot of the simple layered model and Figure 2b illustrates the faulted model. Figures 2c and 2d display the recorded seismogram of the simple and faulted models respectively, which were taken from five virtual seismometers. This synthetic seismogram was then used as the input of the TRM algorithm. The spectra of the recorded seismogram of the simple and faulted models are shown in Figures 2d and 2e, respectively. The next exercise used the artificial seismogram as an input to the TRM algorithm to predict and localize the source point of the virtual microtremors.

Acoustic signals emitted by a source, propagate through medium layers of rock and are recorded by seismometers (receivers) on the surface in the time domain. Modeling back in wave propagation is the reverse process in the time domain from the seismometer transmitted return via the same path on the way to the receiver, to show the location of the source in space and time. In principle, the algorithm of the TRM is the same as the forward modeling of the acoustic FD technique, where the source is positioned in the virtual seismometer location. In this paper, we first assessed the robustness of the TRM algorithm to the synthetic seismogram and then applied it to the real data. In order to verify the accuracy of TRM in handling the real data set, we considered the additional information of reservoir and production data.

3.1 Application to Synthetic Microtremors

Our application of TRM to the recorded synthetic microtremors was performed to verify the accuracy of the algorithm. TRM was proposed to localize the microtremor sources in the subsurface related to the hydrocarbon reservoirs. The synthetic seismogram, which is shown in Figures 2c-2d, was used as the input to the TRM algorithm. This synthetic seismogram represents the particle velocities of the geological model. Our strategy of localizing the microtremor source was based on the concept that hydrocarbons in the subsurface emit a dynamic signal within a certain bandwidth to the recorder on the surface. The microtremor source stands out due to high particle velocities [13]. This means that source location is indicated by high particle velocities commonly corresponding to the high amplitudes of multiple waves, which is constructive interference of signals.

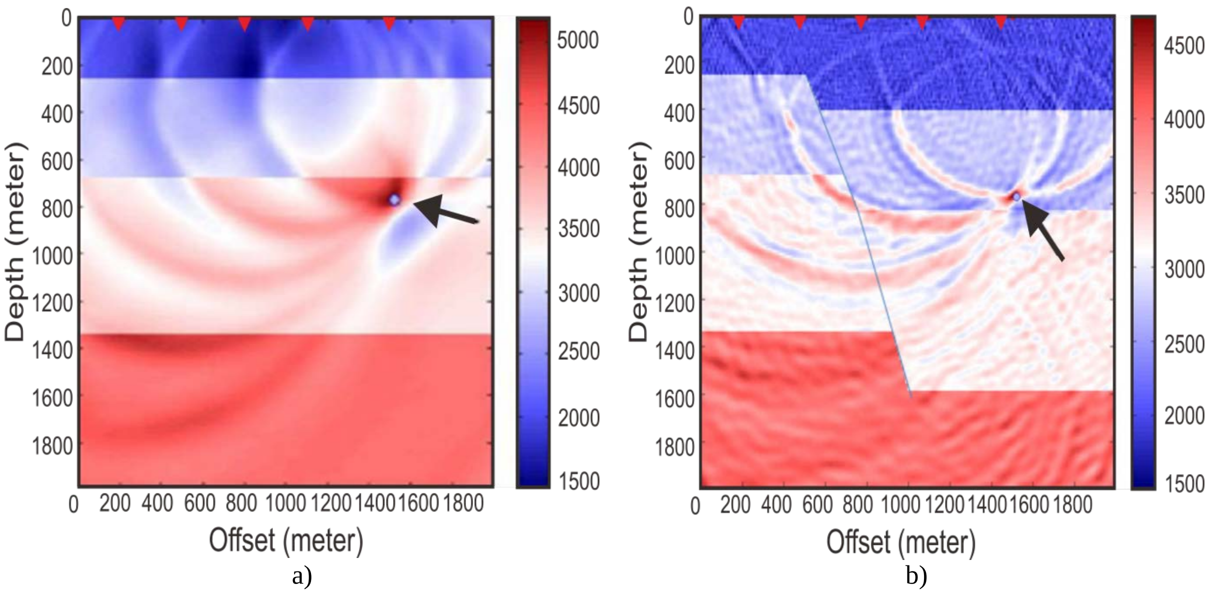


Fig. 3 Simulation results of TRM for synthetic microtremors: a) simple model and b) faulted model. The source point was localized properly as the source of the forward modelling, i.e., at the distance of 1510 m, and at the depth of 770m.

Prior to applying the TRM algorithm, we reversed the recorded synthetic seismogram (Figure 2c-2d), which was prepared as a TRM input. This means that we were propagating back the recorded wave from the seismometers to the subsurface. Figure 3 illustrates a snapshot of the TRM of the recorded microtremor from the seismometers into the subsurface, which shows the result of the TRM in locating the source location based on the synthetic microtremors for the simple (Figure 3a) and the faulted model (Figure 3b). The source location was localized properly in the same position as the source, which used in the forward modeling. The source location is indicated by a focus point, which represents the high particle velocities as illustrated at the distance of 1510 m and at the depth of 770 m.

3.2 Application to Real Microtremors

The TRM algorithm was applied to real microtremor data that was recorded simultaneously by three seismometers. The passive seismic survey was conducted in a production field, which is situated in the southern part of the South Sumatra basin. Administratively, the survey area covers an area of Pagardewa and Karang Agung village, which are located in the western part of the South Sumatra Province. The seismometers were laid out on the surface and with an offset distance of 2870, 4120, and 5460 m. The success of the TRM in localizing the source of the microtremors in the case of synthetic data will be different with the application of the real data. The quality of the recorded data strongly affects the performance of the TRM algorithm in localizing the source of the microtremors.

The seismogram of measured the real microtremors over the production field are shown in Figure 4a, which was recorded for duration of three hours (6.15 am to 9.30 am local time). Recorded data should be selected based on its quality by means of the stability of the recorded energy from three different seismograms. In this case, the real seismogram data was selected only for the duration of a hour recording, which was taken between local time 8.00 am to 9.00 am. The selected data is shown in Figure 4b, shows relatively the same energy for each seismometer. The large amplitude spectrum of each seismometer was similar to each other as shown in Figure 4c. The amplitude spectrum is exhibited at the interval of 1-6 Hz. This situation is consistent with that previously expressed by Broadhead [15] and tested by Ali MY [16], that the oil that resonates with ambient noise in the earth will emit energy back at a similar frequency in which the amplitude of these oscillations is greater than the resonant frequency. In the current study, the TRM was applied to the interval frequency of 1-6 Hz; to localize the source emits the signals.

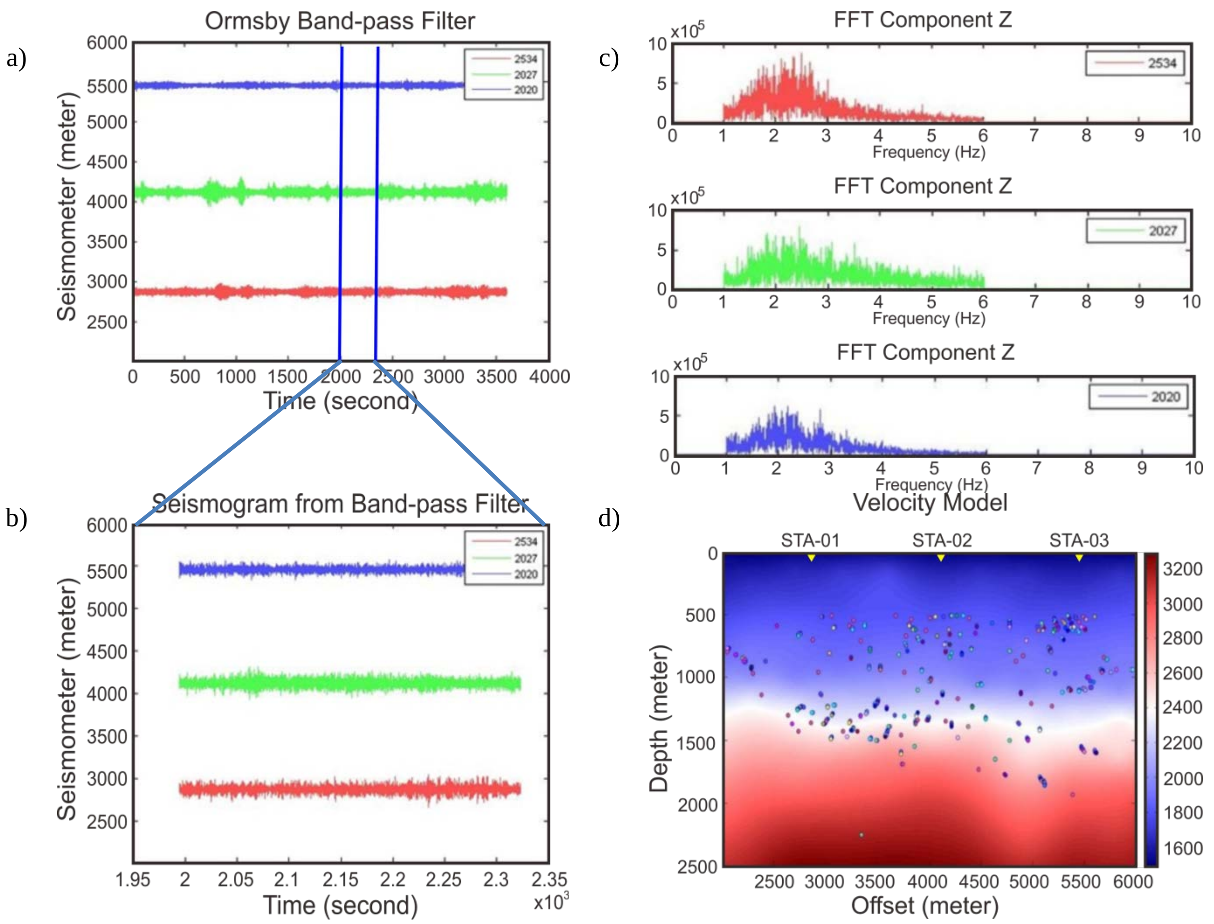


Fig. 4 Application of TRM for real microtremors: a) real seismogram measured period of three hours, b) selected data for a certain period, c) amplitude spectrum of selected data, and d) distribution of high particle velocities, which are associated with the source of the microtremors.

Figure 4d shows the predicted source location based on high particle velocities, which is indicated by the distributed points. In general, it was observed that the highest particle velocities, which are associated with the source location, are not focused toward one point source, but are distributed randomly in the depth range of 700 to 1500 m. Referring to the production field data, this depth range is acknowledged as the reservoir.

4. CONCLUSION

TRM, which was developed from acoustic finite difference modeling, has been successfully applied to synthetic and real microtremor data for localizing the microtremor signal, which is associated with the ground motion of hydrocarbon reservoirs. TRM applied to a synthetic seismogram, which was generated by low-frequency microtremors, successfully detected the source at the same location of the source of the forward modeling. The source location is indicated by high particle velocities that commonly correspond to high amplitudes of multiple waves, which is constructive interference of a signal. TRM applied to a real seismogram, which was recorded over an oil field in the South Sumatra basin, shows good agreement with the spectral anomalies of the microtremor signal that were emitted from the reservoirs. The high particle velocities, which are associated with signals the source location, were not focused toward one point source but distributed randomly in the depth range of 700 to 1500 m.

5. AUTHOR’S CONTRIBUTIONS

A. Haris took the lead in the research project and writing the manuscript. S. P. Silaban and A. Riyanto designed the model and performed the numerical simulation. R. Syahputera acquired the passive seismic data. S. Mardiyati contributed in developing the algorithm. Adriansyah supervised the project.

6. ETHICS

This article is original work and not under consideration for publication in any other journal. There is no conflict of interest on this paper.

7. REFERENCES

[1] Bishop, M. G., South Sumatra Basin Province, Indonesia; the Lahat/Talang Akar-Cenozoic total petroleum system. No. 99-50-S. US Geological Survey, 2000. pp.1-13.

[2] Amier, R. I., "Coals, source rocks and hydrocarbons in the South Palembang sub-basin, South Sumatra, Indonesia." University of Wollongong Master of Science Thesis, 1991. pp.1-161.

[3] Sutriyono, E., Hastuti, E. W. D., and Susilo, B. K., "Geochemical assessment of Late Paleogene synrift source rocks in the South Sumatra basin." International Journal of Geomate, Vol. 11.23, July, 2016, pp. 2208-2215.

[4] De Coster, G. L. “The geology of the central and south Sumatra basins”, in Proceedings of the Indonesian Petroleum Association, 3rd Annual Convention, 1974, pp. 77-110.

[5] Haris, A., Sitorus, R.J., and Riyanto, A."Pore pressure prediction using probabilistic neural network: case study of South Sumatra Basin." IOP Conference Series: Earth and Environmental Science. Vol. 62. No. 1. IOP Publishing, 2017: 012021. pp. 1-6.

[6] Katili, John A. "Geochronology of West Indonesia and its implication on plate tectonics." Tectonophysics, Vol. 19(3), Oct. 1973, pp. 195-212.

[7] Doust, H., and Noble, R.A., "Petroleum systems of Indonesia." Marine and Petroleum Geology Vol. 25(2), Feb. 2008, pp. 103-129.

[8] Dangel, S., Shaepman, M. E., Stoll, E. P., Carniel, R., Barzanji, O., Rode, E. D., and Singer, J. M. “Phenomenology of tremor-like signals observed over hydrocarbon reservoirs”, J. Volcanol. Geothermal Res., Vol. 128, 2003, pp. 135 – 158.

[9] Bloch, G., and Akrawi, K. "Application of passive seismic (IPDS) surveys in Arabian Peninsula." First EAGE Passive Seismic Workshop-Exploration and Monitoring Applications. 2006, A28.

[10] Graf, R., Schmalholz, S. M., Podladchikov, Y., and Saenger, E. H. “Passive low frequency spectral analysis: Exploring a new field in geophysics”, (World Oil, 2007), **228**, 47–52.

[11] Lambert, M., Schmalholz, S. M., Saenger, E. H., and Podladchikov, Y. Y. "Low-frequency anomalies in spectral ratios of single-station microtremor measurements: Observations across an oil and gas field in Austria." SEG Technical Program Expanded Abstracts, 2007. 1352-1356.

[12] Margrave, G. F. "Numerical Methods of exploration seismology with algorithms in Matlab: http://www. crewes.org/ResearchLinks/FreeSoftware/EduSoftware. " NumMeth. pdf (2003). pp. 52-56.

[13] Steiner, B. , Saenger, E.H., and Schmalholz, S.M., "Time reverse modeling of low-frequency microtremors: Application to hydrocarbon reservoir localization." GEOPHYSICAL RESEARCH LETTERS 35 (2008): L03307. pp. 1-7.

[14] Clayton, R., and Engquist, B., “Absorbing Boundary Conditions for Acoustic and Elastic Wave Equations”, Bull. Seis. Soc. Am., Vol. 67, 1977, pp. 1529 – 1540.

[15] Broadhead M. K., “Oscillating oil drops, resonant frequencies, and low – frequency passive seismology”, geophysics, 75(1), Jan.– Feb. 2010, pp. 01-08.

[16] Ali M. Y., Berteussen K. A., Small J., and Barkat B. “Low- frequency passive seismic experiments in Abu Dhabi, Uni Arab Emirates : implications for hydrocarbon detection”, (European Association of Geoscientists and Engineers, Geophysical Prospecting, 2009), pp. 1 – 25.