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Innovation of Hydrocarbon Investigation Using Audio-Magnetotelluric in Cepu Field, Indonesia

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Abstract

An audio-magnetotelluric (AMT) survey has been performed at Cepu oil field located in Indonesia. The objective of this research is to detect resistivity structures of this important hydrocarbon rock. This research can be classified as an innovation in application of the AMT method for hydrocarbon exploration. The lack of seismic resolution has been provided by the AMT method, especially in the location of sub-basalt and sub-salt plays. In additional, the cost of AMT survey is quite low compared to seismic. The forward modelling is included in this research to understand the measurement data response from a mathematical model. In the field campaign, AMT data were acquired along two profiles in a frequency range of 0.1 to 8000 Hz. Anticlinal structure that has an E-W trend has also been identified by AMT resistivity model. Analyses of the AMT data suggest signatures of hydrocarbon reservoir from the anticlinal structure that indicated by a low resistivity zone. The basement structure is estimated to be located at 1600 m or deeper. This study concludes that, as far as the hydrocarbon prospects are concerned, the AMT results seem to confirm the continuation of the anticlinal structure, which was identified as the primary hydrocarbon prospect in previous studies.

Abstract

Inovasi Penggunaan Metode Audio-magnetotelurik pada Investigasi Hidrokarbon di Lapangan Cepu, Indonesia. Sebuah survei audio-magnetotelurik (AMT) telah dilakukan di lapangan minyak Cepu di Indonesia. Tujuan dari penelitian ini adalah untuk mendeteksi struktur resistivitas dari batuan hidrokarbon di sana. Penelitian ini dapat diklasifikasikan sebagai sebuah inovasi dalam penerapan metode AMT untuk eksplorasi hidrokarbon. Kekurangan pada resolusi seismik telah disediakan oleh metode AMT, terutama di lokasi yang terdapat sub-basalt dan sub-salt. Selain itu, biaya survei AMT cukup rendah dibandingkan dengan seismik. Pemodelan ke depan termasuk dalam penelitian ini dilakukan untuk memahami respon data pengukuran dari model matematis. Di lapangan, data AMT diperoleh disekitar dua profil dalam rentang frekuensi 0,1 sampai 8000 Hz. Struktur antiklinal yang memiliki tren E-W juga diidentifikasi menggunakan model resistivitas AMT. Analisis-analisis data AMT menunjukkan tanda-tanda reservoar hidrokarbon dari struktur antiklinal yang ditunjukkan oleh zona resistivitas rendah. Struktur dasar diperkirakan berada pada kedalaman 1600 m atau lebih. Studi ini menyimpulkan bahwa sejauh menyangkut prospek hidrokarbon, hasil-hasil AMT tampaknya mengkonfirmasi penerusan struktur antiklinal, yang diidentifikasi sebagai prospek hidrokarbon utama pada penelitian sebelumnya.

Keywords: audio-magnetotelluric, exploration, hydrocarbon, resistivity

1. Introduction

In recent years, electromagnetic (EM) methods have been applied in hydrocarbon exploration, particularly audio-magnetotelluric (AMT) method. The AMT method is mainly used as a complement of seismic reflection method. The lack of seismic resolution has been provided by that AMT method, especially in the location of sub-basalt and sub-salt plays. The AMT method can differentiate structures and hydrocarbon formation based variation in resistivity value, while the seismic method is unable to do that. Additionally, the cost of AMT survey is quite low compared to seismic.

In some previous studies, EM methods have been used in hydrocarbon exploration and mapped geology structures. For example, CSAMT (Controlled source audio-magneto-telluric) and AMT for hydrocarbon exploration in Egypt [1]) and RMT (Radio magnetotelluric) and TEM (Transient electromagnetic) for mapping active faults in Northern

Greece [2]. Those methods give a good overview of the structures and/or allow determination of the hydrocarbon reservoir.

This study took place in the Cepu oil field, Blora, Indonesia. The location is in the region of North East Java Basin which represents one of the most prolific and maturely explored hydrocarbon basin in Indonesia. The geographical location of the Cepu area is shown in Figure 1. This paper discusses the results of our AMT investigation and the interpretation of the hydrocarbon prospect in the area. In addition, the result from forward modelling also included.

Magnetotelluric Concepts. Audio-Magnetotelluric (AMT) method is an electromag-netic geophysical exploration technique that determines the resistivity of the earth at subsurface depths. The MT signals are generated from two resources. At the high frequency (greater than 1 Hz), the source of the signal is from thunderstorm activity. The lower frequency (less than 1 Hz), the energy originated from the interaction of the earth's magnetic field with the solar wind.

The AMT method measures total electromagnetic field, there are electric (E) and magnetic field (B) variations. The ratio of their intensity termed as the impedance (Z) which is characteristic measure of the electromagnetic (EM) properties of the sub surface medium.

$$Z = \frac{E}{H} \tag{1}$$

Z= impedance [VA^{-1}]
E= electric field [Vm^{-1}]
H= magnetic intensity [Am^{-1}]

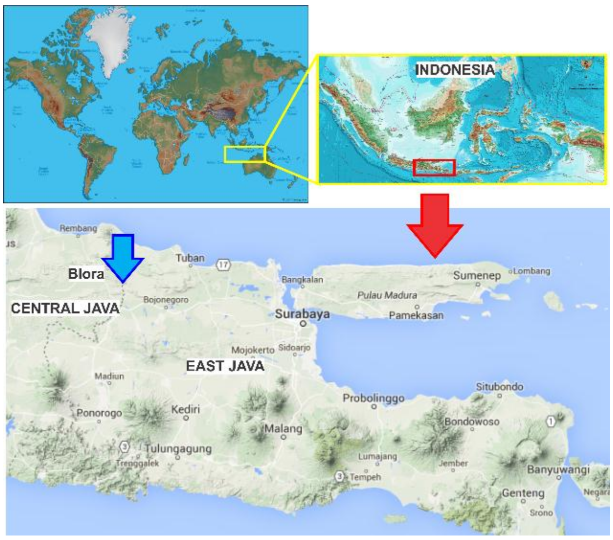

Figure 1. Research Area Located in Central Java, Indonesia (Yellow and Red Box). Location Map of the Cepu Field is Indicated by Blue Arrow

Impedance is often described as apparent resistivity and phase:

$$\rho = \frac{1}{\omega\mu_0}|Z|^2 \qquad \varnothing = tan^{-1}\left(\frac{Im\,Z}{Re\,Z}\right) = 45° \tag{2}$$

ρ = resistivity [$\Omega m = Vm^{A-1}$]
ω = angular frequency [s^{-1}]
μ_0 = magnetic permeability of free space [Hm^{-1}]
$\varnothing$ = magnetotelluric phase [°]

Skin depth or depth of penetration is defined as the depth at which the amplitude of signal have fallen to 1/e of their surface amplitude at the surface. The skin depth is used as rough estimation of the investigation depth of the AMT system and given by [3]:

$$\delta = 500\sqrt{\frac{\rho}{f}}\ [meter] \tag{3}$$

δ = skin depth [m]
f = frequency [Hz]

The petroleum system model will be generated with synthetic and inversion models. Forward modelling is the process of estimating geophysical data as a result based on the calculation of a synthetic earth model. Whereas, inversion is the process of transforming geophysical data measurement into an earth model.

The algorithms that used for 1D inversion are Marquardt, Occam R1, and Occam R2. Marquardt algorithm is identic as a non-linear inversion with damped least square [4]. Occam algorithm is an inversion with smoothness constrained in its model. R1 and R2 is the smoothness criteria with different definition in calculating between adjacent layers [5].

In determining how accurately the result of inversion, particularly from Marquardt inversion, there is a value that we can discuss called importance. According to Widodo [6], importance values is the information about the resolution of a model parameter that is obtained from the second order of Marquardt algorithm that using singular value decomposition (SVD). Importance values of resistivities and thickness were calculated in order to get better assessment of the resolution of model parameters. If the importance value is higher, the model parameters will resolve better. It can be classified into three groups. The model parameters are well resolved if the value is more than 0.80, shaky if the value is between 0.50–0.80, and unresolved for value less than 0.50.

The algorithm that will be used in 2D inversion is NLCG (Non-Linear Conjugate Gradient) algorithm. The scheme of NLCG is to minimize an objective function that penalizes data residuals and second spatial derivatives of resistivity, which can be denoted as [7]:

$$\Phi(m) = (d - G(m))^T V^{-1}(d - G(m)) + \tau m^T L^T Lm \quad (4)$$

Φ = objective function
$\boldsymbol{d}$ = measured data
G = forward modelling function
$\boldsymbol{V}$ = weighting matrix
τ = regularization parameter
$\boldsymbol{L}$ = second order smoothness operator
$\boldsymbol{m}$ = model parameter

In the ideal 2-D case, electric and magnetic fields are mutually orthogonal. Therefore, we can decoupled into two independent modes; one incorporating electric fields parallel to strike (Transverse electric or TE mode), the other incorporating magnetic fields parallel to strike (Transverse magnetic or TM mode) [8].

Tectonic and Geologic Setting. North East Java Basin is a back-arc basin which dominated with anticline, syncline, and fault structures. This basin can be classified as a classic back-arc basin and the most structurally and stratigraphically complex of Indonesian back-arc basins.

The North East Java Basin can be separated to four block differentiated on the basis of fold orientation, faulting, and outcrop distribution [9]. Block 1 considered as the oldest surface sedimentary rocks (Figure 2a).

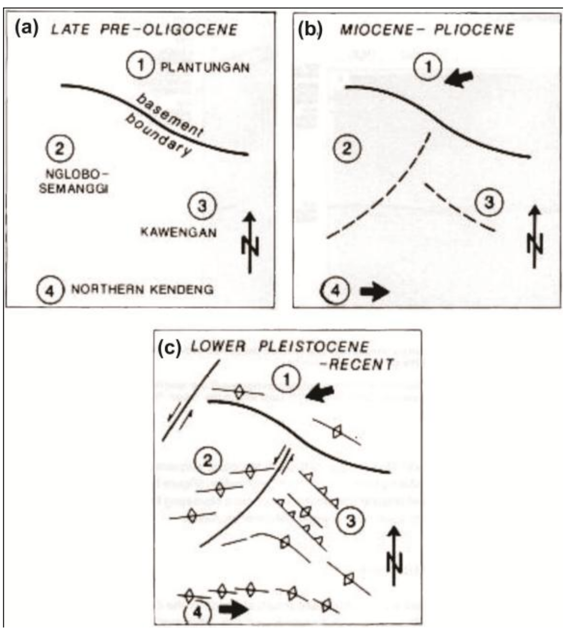

Figure 2. Four Blocks Differentiated on the Basis of Fold Orientation, Faulting, and Outcrop Distribution in the North East Java Basin [9]

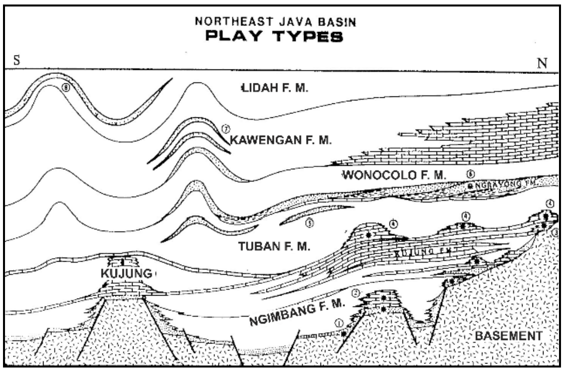

Figure 3. The North East Java Basin Play Types [9]

Block 2 is separated from Block 3 by a major sinistral fault (Figure 2b & 2c). Block 2 in the western section of the oil fields has mainly E-W trending folds while Block 3 to the east consists with NW-SE trending folds (Figure 2c). Block 4 in the southern of oil fields exhibits deeper basement and has E-W trending folds.

According to Doust and Noble [10], several of those basins contains hydrocarbon accumulations while several other represent, as yet, frontier provinces. Mainly, the hydrocarbon reservoirs are located in sandstones and calcareous sandstones of the early post-rift and one of them is Wonocolo formations. The North East Java basin play fields is shown in Figure 3. The Wonocolo formation is the targeted formation in this research.

2. Methods

The equipment used during the acquisition data was the Zonge GDP-32 with two horizontal components of electric field (E_x and E_y) and two components of magnetic field (H_x and H_y) that are recorded. The sites were distributed along two profiles and in a frequency range of 0.1 to 8000 Hz. The first profile has a NW-SE direction with 5 sites and the second profile has a N-S direction with 4 sites. The stations on profile 1 are 15, 3, 4, 12, and 9, whereas the stations on profile 2 are 16, 2, 4, and 8, The illustration of AMT unit setup is shown in Figure 4 and the AMT measurement stations in the Cepu field can be seen in Figure 5. Because of some obstacles in the field, the space between porous pot and MT Unit was only 25 m. The magnetic coil of Hz was not used because the analysis of vector induction will not be conducted.

Data processing was performed using Marquardt and Occam algorithm for 1D inversion and NLCG (Non-linear conjugate gradient) for 2D inversion. The forward modelling was also included in this research to understand the measurement data response from a mathematical model. The anticline structure which is associated with petroleum trap has been modelled in 1D and the

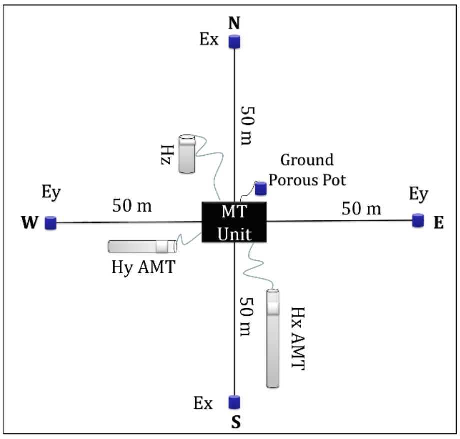

Figure 4. Setup of MT Unit

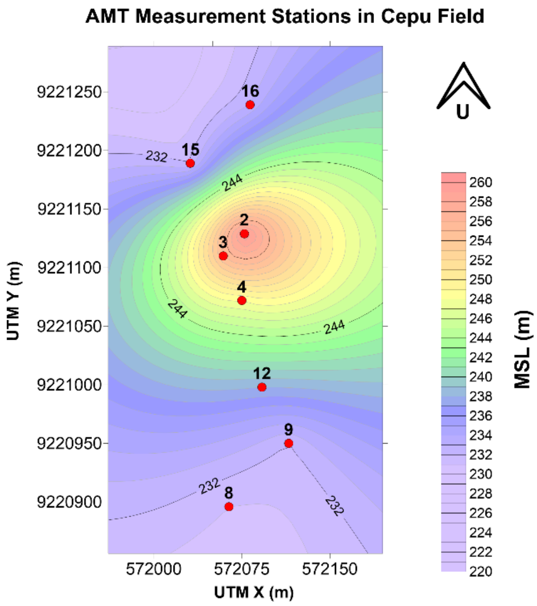

Figure 5. AMT Measurement Stations in Cepu Field

conductive body inside the starting model has been modelled in 2D model. The conductive body represented a hydrocarbon rock which has a low resistivity.

3. Results and Discussions

Figure 6 and 7 show the illustration and 1D synthetic resistivity model of petroleum system with anticline structure trap. The responses of apparent resistivity and phase curve are shown in Figure 3. We compared the response from station A and B. The station A (Figure 8) represented the limb of the anticline without hydrocarbon reservoir while the station C (Figure 9) represented the crest of the anticline with hydrocarbon reservoir. From the apparent resistivity curve at station A, the hydrocarbon reservoir was detected in the frequency range of 4–200 Hz and it was followed by significant change in phase.

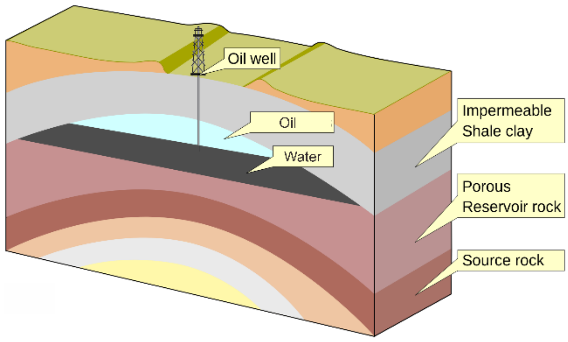

Figure 6. Illustration of Petroleum System with Anticline Structure Trap

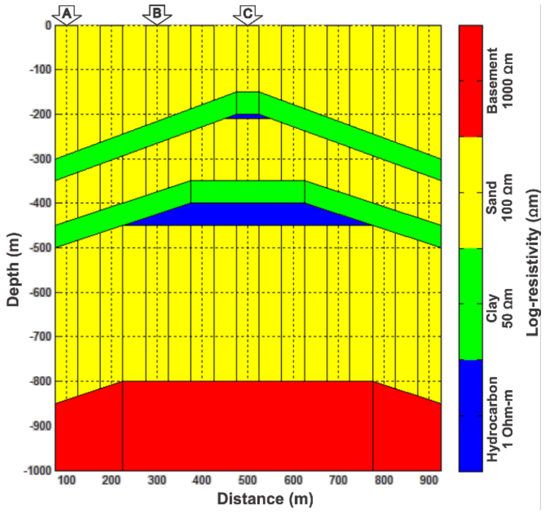

Figure 7. Synthetic Model of Petroleum System with Anticline Structure Trap

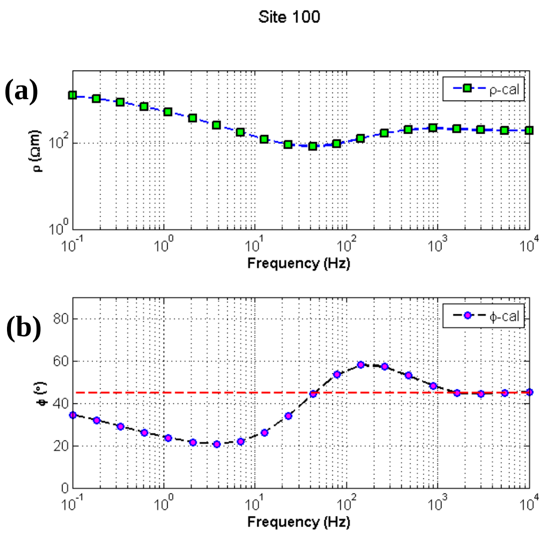

Figure 8. Response of AMT Data from Synthetic Model at Station A: (a) a Frequency – Apparent Resistivity Graph and (b) a Frequency – Phase Graph

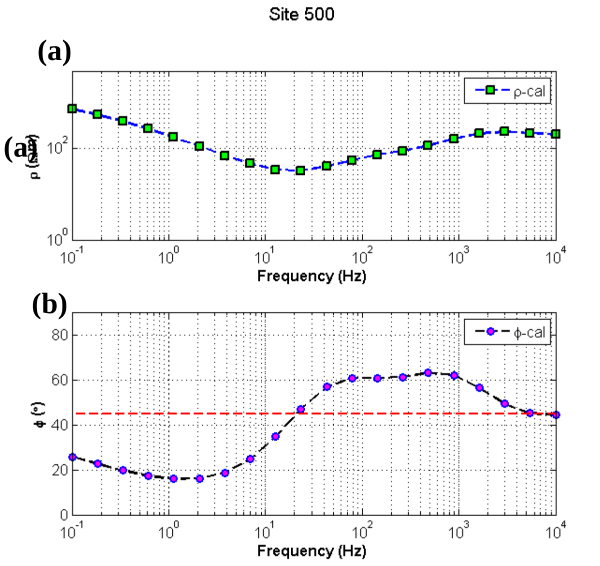

Figure 9. Response of AMT Data from Synthetic Model at Station C: (a) a Frequency - Apparent Resistivity Graphand (b) a Frequency – Phase Graph

As already described in basic theory, we can decoupled 2D AMT data into two independent modes. The TE mode describes currents flowing parallel to strike. As a consequence of the discontinuous object in the subsurface, TE mode tend to resolve lateral conductivity. However, the TM mode describes currents flowing perpendicular to strike. TM mode can be used to diagnose lateral conductivity on y-axis variations better than TE mode.

Figure 10 shows a synthetic model with a horizontal conductive body which is represent a hydrocarbon reservoir. The resistivity value of starting model was 50 Ωm while the conductive body was 5 Ωm. There was no strike on that model because the conductive body is on lateral position. From that synthetic model and its response, it can be seen that TE mode is more sensitive than TM mode. The resistivity and phase curve of TE mode significantly changed at frequency 10 Hz or less. The response of AMT data can identified that conductive body was located at depth around 200–400 m and at the further depth the layer was more resistive.

Figure 11 shows the result from Marquardt, Occam R1, and Occam R2 inversion. The first and second order smoothness constraints of the Occam inversion generated smoother model relative than Marquardt inversion.

However, the hydrocarbon reservoirs were indicated from conductive layer at the depth 160-210 m, 410-530 m, 1030-1060 m.

The result of Marquardt 1D inversion on profile 1 can be seen in Figure 12. This profile consisted of 5 stations and has a NW-SE direction. The resistivity model obtained from AMT data showed the depth was up to 2000 m and indicated a complex structure.

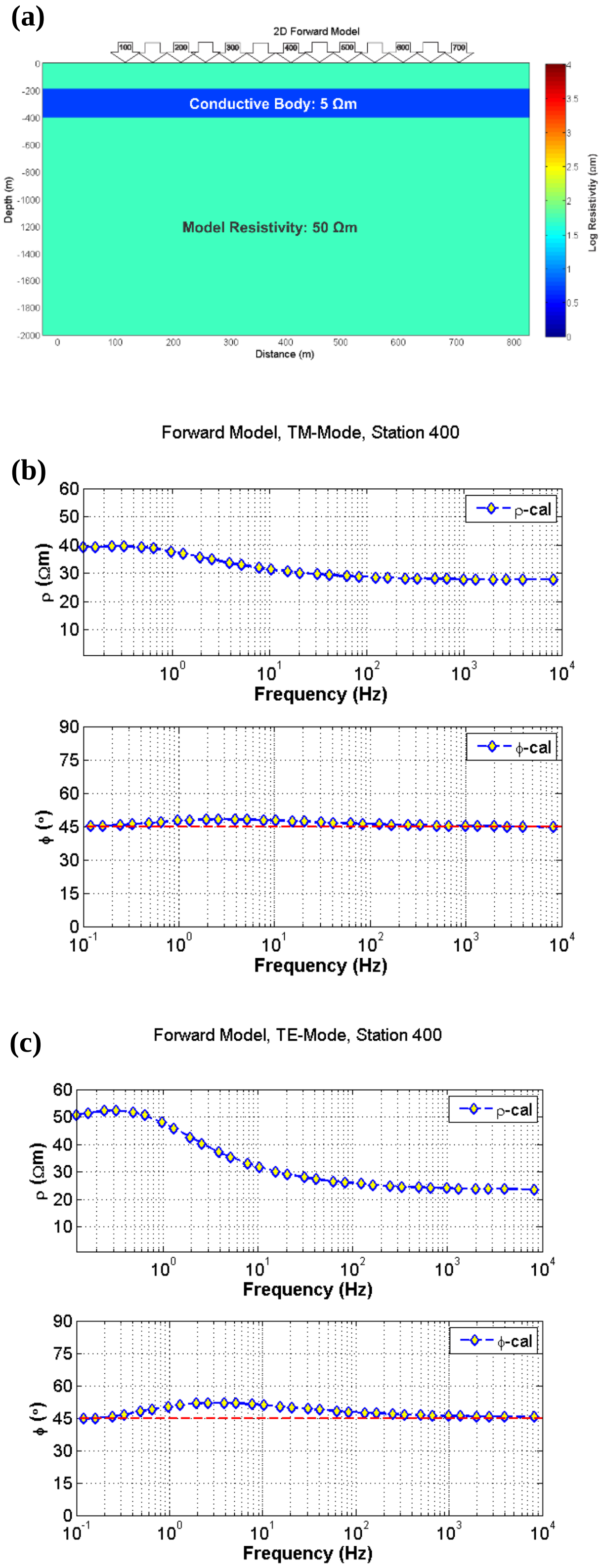

Figure 10. (a) Synthetic Model with Horizontal Conductive Body, (b) Response of AMT Data with TM Mode, and (c) Response of AMT Data with TE Mode

The result of 1D resistivity model on profile 2 can be seen in Figure 13. This profile consisted of 4 stations and has a N-S direction. From the surface to depth of 160 m, the resistivity model represented limestone intercalation with sandstone and claystone with resistivity value around 5–40 Ωm. There were some conductive layers with various depth. The conductive layers (~1 Ωm) formed an anticline structure at the depth 160 and 490 m. The anticline structure was indicated as a petroleum trap on this area. The basement was estimated to be located at 1600 m or deeper and indicated by high resistivity zone.

Distribution of importance values of resistivity and thickness on profile 2 is shown in Figure 14 and 15 respectively. The best result is from station 2 which has a high importance value of resistivity and thickness. The importance values were close the value of 1.

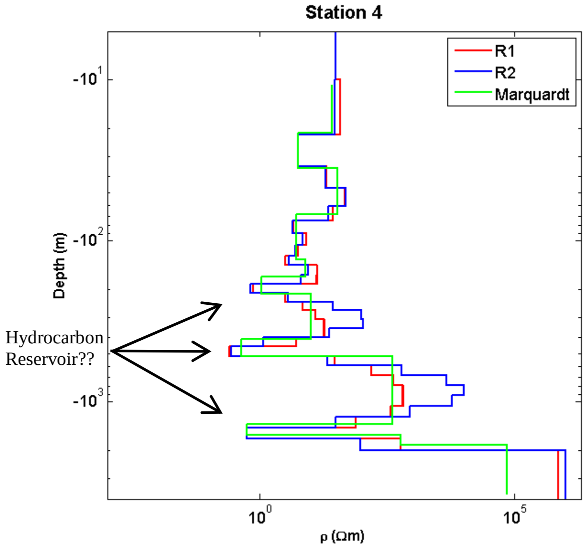

Figure 11. Results of 1D Resistivity Model Using Occam R1, Occam R2, and Marquardt Algorithm at Station 4

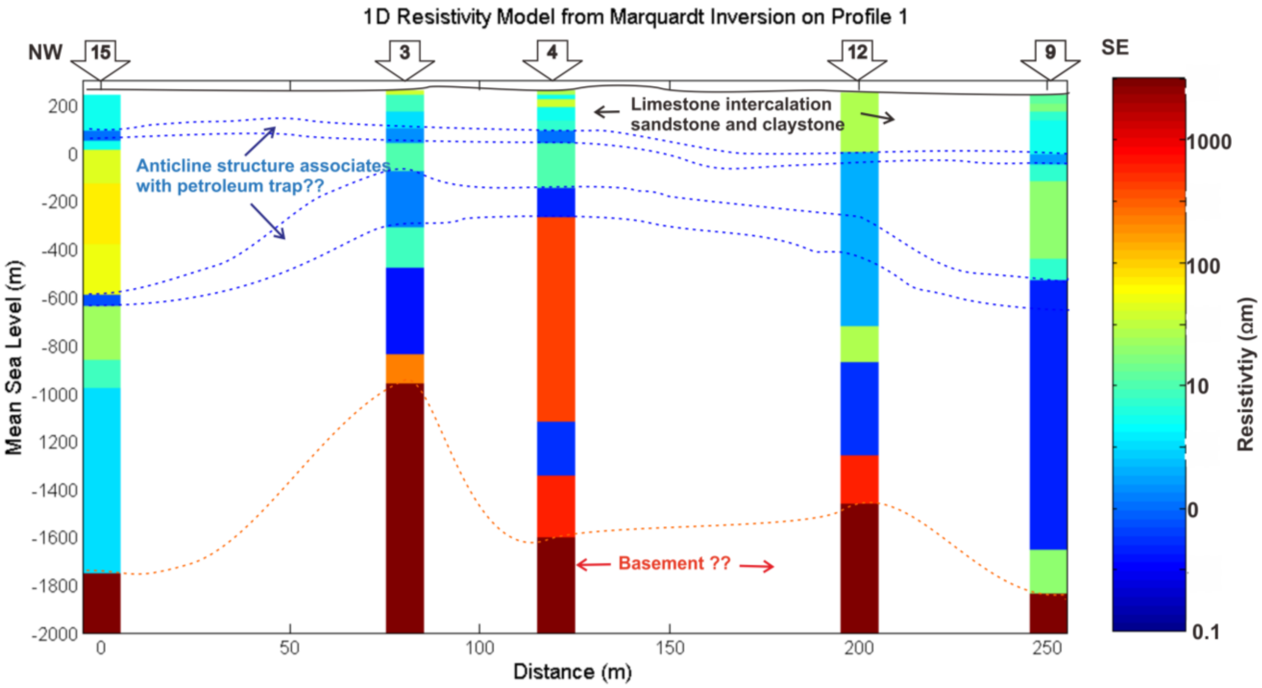

Figure 12. Results of 1D Resistivity Model Using Marquardt Algorithm on Profile 1

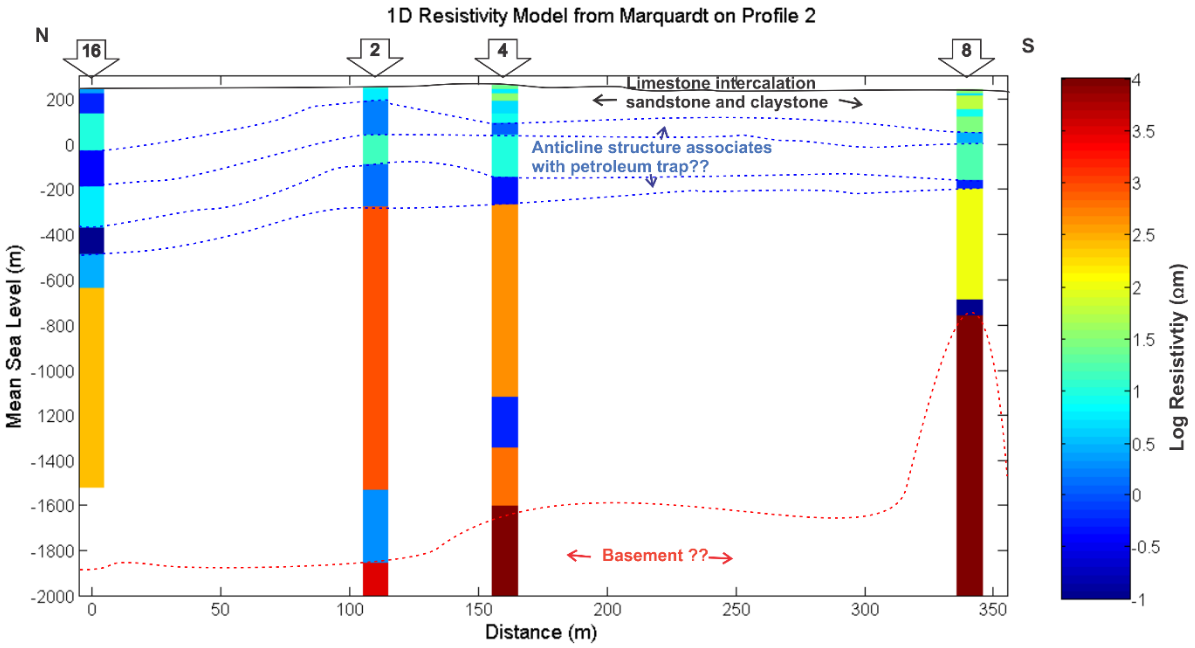

Figure 13. Results of 1D Resistivity Model Using Marquardt Algorithm on Profile 2

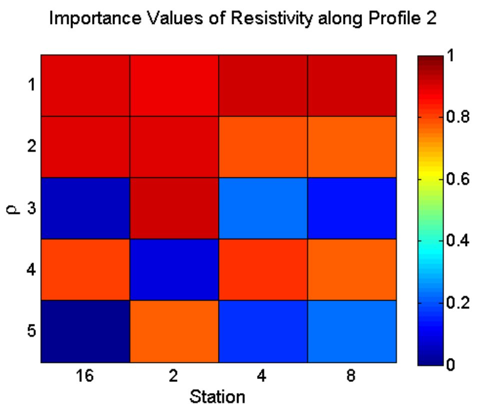

Figure 14. Importance Values of Resistivity from Each Station

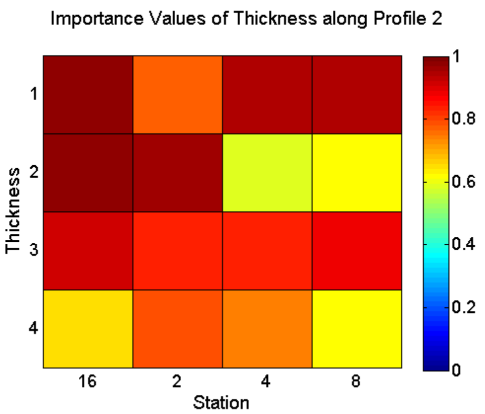

Figure 15. Importance Values of Thickness from Each Station

The station 16, 4, and 8 shows a good result by the importance values is dominated by red colour which mean close to the value of 1. From that importance values of AMT data, we can concluded that the result of 1D inversion can represents the subsurface properly.

The result of NLCG 2D inversion on profile 2 is shown in Figure 16. It can be seen at 0 to 100 m depth represented by limestone intercalation with sandstone and claystone. The anticline structure was found underneath profile meters 100–210 m. As explained in the 1D model interpretation at profile 2, the 2D model at the same profile showed that the anticline structure has a low resistivity zone and associated with petroleum trap. The basement structure has a high resistivity and the depth was estimated at 2000 m or deeper.

The results from 1D and 2D resistivity model were consistent with the tectonic subdivision in Cepu that can be seen in Figure 17. The location of study was on the block no. 2 (western section) and presence of abundant E-W trending folds.

The results also have a good correlation with the comparison between AMT, MT, models, and mud logging data which are indicated the depth and thickness of reservoir rock [12] that is shown in Table 1. The study from Widodo et al. [12] also indicated the reservoir rock in the petroleum system was formed an anticline structure.

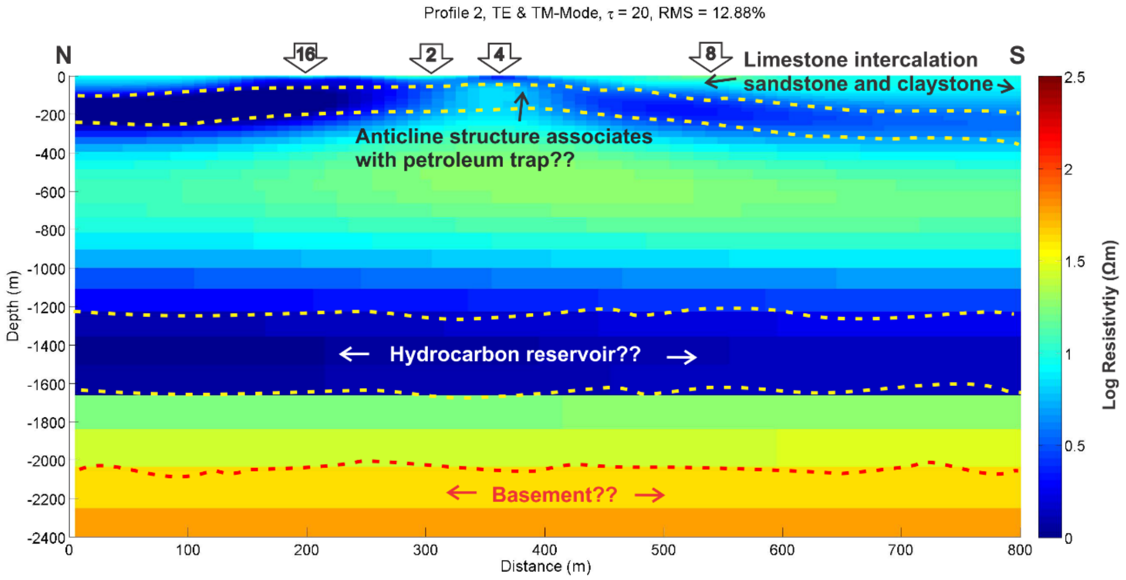

Figure 16. Result of 2D Resistivity Model with Joint Mode (TE & TM-mode) on Profile 2

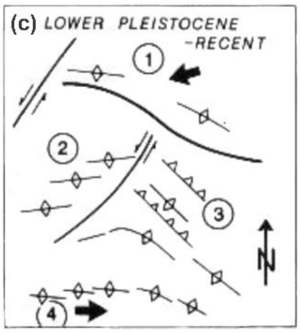

Figure 17. Four Block Tectonic Structures of the Cepu Region [9]

Table 1. Comparison between AMT, MT Models, and Mud Logging Data which are Indicate Reservoir Rocks [8]

AMT and MT Models		Mud Logging Data	
Depth (m)	**Thickness (m)**	**Depth (m)**	**Thickness (m)**
190	10	194	8
280-380	100	300-330	30
2000	150	345-400	55
		490	5

4. Conclusions

The analyses of 1D AMT models suggest signatures of anticline structure at depth 160 and 490 m. However, the 2D AMT models suggest of an anticline structure at a depth 100-210 m. The anticline structure that have low resistivity zone is indicated as a petroleum trap in the area. The existence of hydrocarbon reservoir seems to be confirmed by the result of the AMT survey. The AMT survey could become an alternative method used in hydrocarbon investigation.

References

[1] Younis, G. El-Qady, M.A. Alla, M.A. Zaher, A. Khalil, M. Al Ibiary, A. Saraev, Arabian J. Geosci. 8/4 (2015) 1965.
[2] K. Vozoff, Geophysics, 37/1 (1972) 98.
[3] D.W. Marquardt, J. Soc. Ind. Appl. Math. 11/2 (1963) 431.
[4] S.C. Constable, R.L. Parker, C.G. Constable, Geophysics. 52/3 (1987) 289.
[5] Widodo, B. Tezkan, Procedia Earth Planet. Sci. 12 (2015) 68.
[6] Widodo, W. Procedia Earth Planet. Sci. 12 (2015) 63.
[7] W. Rodi, R.L. Mackie. Geophysics, 66/1 (2001) 174.
[8] F. Simpson, K. Bahr, Practical Magnetotellurics. Cambridge University Press, United States, 2005, p.254.
[9] N. Soeparyono, P. Lennox, Explor. Geophys. 22/2 (1991) 369.
[10] H. Doust, R.A. Noble, Mar. Pet. Geol. 25/2 (2008)103.