

# Electro telluric resonance logging

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**Abstract.** Electro telluric resonance logging (ETR-Logging) uses the naturally-occurring electric currents flowing through the rock strata within the body of the Earth to obtain information in regard with the electrical structure of the rock layers. An orthogonal configuration of ground antenna oriented NS and WE and the corresponding electronic circuitry are used for capturing the telluric signals. The position of the logging point is located at the centre of the orthogonal ground antenna. Deep bore holes are not required. The workings of the ETR-Logging follow the principle of the resonance between two signals and the skin-depth effects. The operating mechanisms of the ETR-Logging also conform with the Ohm's Law. A stratum with high resistivity characteristics, such as a saturated oil-bearing formation, gives high amplitude of resonance response and a wide range of phase angle variation of telluric energy. A stratum with low resistivity characteristics such as saline-water-filled sands, gives low amplitude resonance response and wide range phase angle variation. ETR-Logging at three locations in North Kalimantan and one location South Kalimantan, demonstrate the results of this technique. It is effective in predicting the present and the abundance of the deposits as well as verifying the quality of the seals.

## 1. Introduction

Passive electromagnetic exploration techniques using naturally-occurring telluric energy have been employed in the search for petroleum, geothermal and mineral resources since 1950's [1,2]. The most notable method is the magneto-telluric [3,4], which became extensively used in exploration for oil and geothermal deposits since 1980 as well as searching for minerals [5] and coal bed methane [6]. More recent practices of using the telluric currents for the search of oil deposits have been considerably simplified in terms of the instrumentation, by only sensing the vertical component of the electrical field [7,8]. Very recently, the use of the telluric currents method goes airborne, capable of mapping broad areas on-land as well as off-shore [9]. All the passive electromagnetic methods stated above record mainly the amplitude of the telluric energy, where a high amplitude response corresponds to high level electric fields across the measuring electrodes. The high amplitude of resonance response correlates with a high resistivity stratum. This high resistivity stratum however, may or may not represent oil-bearing formation. Only stratum with a high amplitude resonance response and a wide range of phase angle variation [10,11] indicate a highly saturated hydrocarbon-bearing formation. The present work employs a phase-synchronized signal-detection system to acquire information in regard with the present and the abundance of oil deposits as well as examining the quality of the seal rocks.



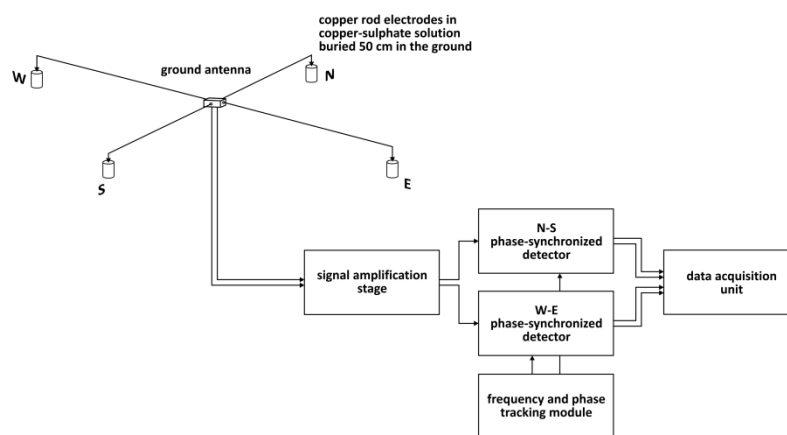
## 2. Methods

The ETR-Logging follows the principle of the resonance between two signals, the telluric signal and the tracking signal. The measurements aim at obtaining the amplitude of the resonance response and the variation of phase angle of telluric energy vectors. By incrementing the tracking steps throughout the frequency bands, a log of resonance response and variation of phase angle at each frequency can be acquired. The working mechanisms of the ETR-Logging follow the principle of the skin-depth effects and conform with the Ohm's Law. A stratum with high resistivity, such as oil-bearing and highly saturated reservoir, gives high amplitude of resonance response and a wide range phase angle variation. A stratum with low resistivity, such as saline-water-filled sands, gives low amplitude resonance response wide range phase angle variation as well. A stratum which contains smaller amount of hydrocarbon fluids, *i.e.* low saturation reservoir, gives low amplitude of resonance response but still shows a significantly wide range phase angle variation resulted from ionic activities of hydrocarbon fluids [11]. Low amplitude resonance response and narrow range phase angle variation characterize a stratum of bearing no hydrocarbon fluids. High amplitude resonance response and narrow range phase angle variation suggest a solid and dry stratum. Table 1 summarizes the status of stratum pertaining to amplitude of resonance response and phase angle variation of telluric energy.

**Table 1.** Electro telluric resonance response and phase angle variation of Earth stratum

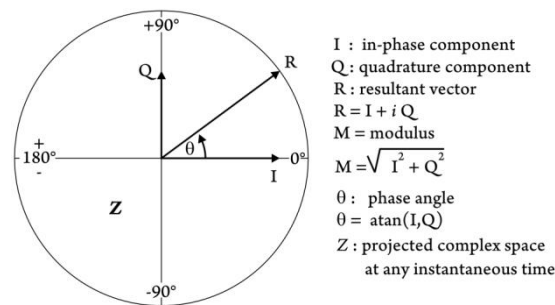
Resonance response (mV/km)	Phase angle variation (°)	Status of stratum
high	wide	highly saturated reservoirs
low	wide	low saturation reservoirs
low	narrow	stratum bearing no oil
high	narrow	solid and dry rocks

The ETR-Logger consists mainly of ground antenna and the corresponding electronic circuitry. The antenna consists of two spreads of coaxial cables oriented in NS and WE directions, approximately 100 metres in length, each. The logging procedures deal mainly with the measurements of the in-phase and the quadrature-phase components of telluric signals. The analysis of resonance response and phase angle variation aims at determining the distinct contrast between the target of interest against other features along the logs. The functional block diagram of the ETR-Logger is shown in (Figure 1).



**Figure 1.** Functional block diagram of ETR-Logger

Each sample in the measurements of the telluric signals consists of two perpendicular vectors, the in-phase component (I) and the quadrature-phase component (Q). The measured signal at any instantaneous time is the projection of the three-dimensional single-frequency telluric signal on a two-dimensional complex plane [12] (Figure 2).



**Figure 2.** Illustrating the phase angle  $\theta$  and the Modulus  $M$  of the telluric energy vector  $R$  and the corresponding components of the in-phase  $I$  and the quadrature-phase  $Q$  on a complex plane  $Z$  (Adapted from Bracewell, 1978).

### 3. Results

The ETR-Logging in Sajau Area, North Kalimantan were conducted in May-June 2016. The measurements at three locations include the Mahatma-1 well, Sumur Belanda-3 (old Dutch Well-3) and Seberaba-3. The Mahatma-1 was drilled in 2014, oil was found at 710 meters below ground surface. Sumur Belanda-3 is not drilled but located 70 metres south of Gandi-1N well, which was drilled in 2015 but found to be dry. Results of the ETR-Logging in Sajau Area are presented in Figs 3 through 5. The ETR-Logging in Tanjung Area was carried out in August 2015. It was planned to be carried out at one or more recognized production wells which operate in the area. However, it was unable to be done due to the failure of obtaining a formally written permission from the authorized body. However, considering the tight schedule while concurrently doing the gravity surveys in the area, a location was selected for the ETR-Logging. The location of the measurements was given an identification B-09X. Results of ETR-Logging at B-09X are presented in Figs 6.

#### 3.1. Mahatma-1 well

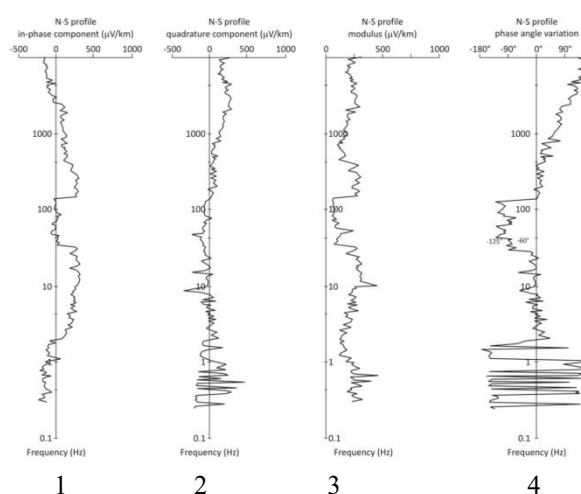
The ETR-Log of the Mahatma-1 well is shown in Figure 3, the NS profile in Figure 3a and the WE profile in Figure 3b. Similarly, on the WE profile, Figure 3b1 depicts the in-phase components, Figure 3b2 depicts the quadrature-phase components, Figure 3b3 depicts the modulus and Figure 3b4 depicts the phase angle variation of the telluric energy along the logs. Figure 3c demonstrates the construction of resistivity and depth logs based on the skin-depth principles.

Along the ETR-Logs of Mahatma-1 well, the NS profile of the resonance response energy appears to be more sensitive than the WE profile but in terms of log signatures, both the NS and WE profiles almost identically show the features in regard with the occurrence of oil deposits. Therefore, for the purpose of the discussion to follow, the modulus and the variation of phase angle of the NS profiles were used to analyse the ETR-Logs of Mahatma-1 well, Sumur Belanda-3 and Seberaba-3. The construction of depth and resistivity logs on the skin-depth chart will also make use of the modulus and the phase angle variation of the NS profiles.

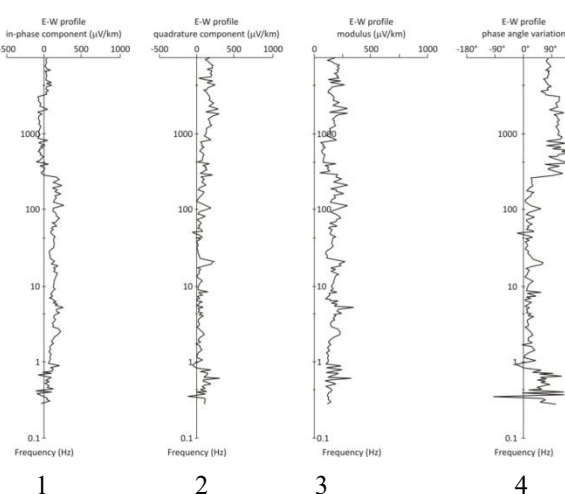
Figure 3c1 depicts the modulus resonance response of the NS profile (dashed line) along with the outline of the interpreted intensity of the telluric energy (solid line) and the corresponding values of resistivity. The resistivity values were estimated based on the Ohm's law, where resistivity is directly proportional to intensity of the telluric energy. Similarly, the resistivity values for constructing the resistivity and depth logs of Sumur Belanda-3, Seberaba-3 as well as B-09X were estimated from the Ohm's law. Figure 3c2 shows the variation of phase angle of the telluric vectors along the log. Figure 3c3 demonstrates the drawings of the resistivity profile (solid line) guided by the resistivity constraint (dashed line) on the skin-depth chart to construct the logs of resistivity and depth (Figure 3c4). The resistivity constraint is dictated by the tracking frequency and the depth where oil is found at the Mahatma-1 well. The tracking frequency at which an adequate contrast of resonance response and a wide range variation of phase angle is identified at 0.8 Hz. The depth at which oil is found in the Mahatma-1 well is 710 m. When computed using the skin-depth formulae, the value of 1.6  $\Omega\text{m}$  for the

resistivity constraint proves to be the closest match to satisfy the depth level of 710 m. The resistivity constraint of  $1.6 \Omega\text{m}$  was therefore, used for constructing the depth and resistivity logs of the Mahatma-1 well, the Sumur Belanda-3 and the Seberaba-3 as well as exercised for the B-09X site in Tanjung Area, South Kalimantan.

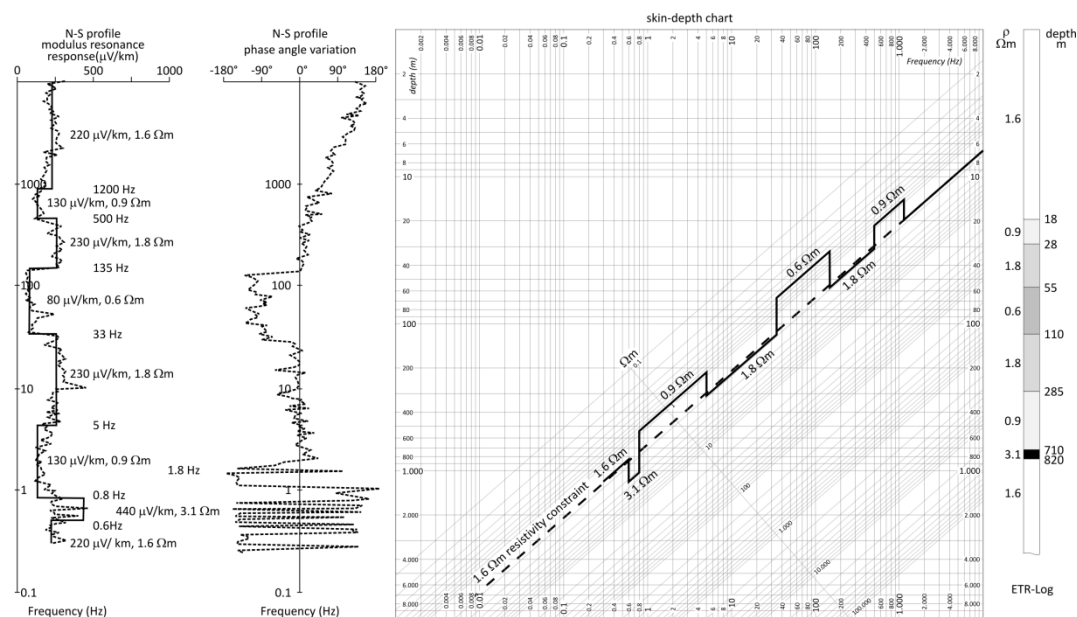
The top-most stratum on ETR-Log of Mahatma-1 (Figure 3c1) is characterized by a low level magnitude resonance response,  $220 \mu\text{V/km}$ , extending from 10.000 Hz down to 1200 Hz. This stratum is also characterized by a narrow range of phase angle variation. This section of the log is interpreted as to represent a dry stratum. The lower stratum to follow extends from 1200 Hz down to 500 Hz. Phase angle varies slightly wider but considered as a narrow range,  $+10^\circ$  to  $+70^\circ$ , the magnitude of resonance response decreases to  $130 \mu\text{V/km}$ , on average. This section of the log is interpreted as to characterizes the near-surface ground water. The stratum which extends from 500 Hz down to 135 Hz is characterized by a little increase in the magnitude of resonance response, averages at  $230 \mu\text{V/km}$ . Phase angles are almost unchanged, averages at  $+10^\circ$ . This section of the log is interpreted as a dry stratum. The stratum which extends from 135 Hz to 33 Hz shows a decrease in the magnitude of resonance response to  $80 \mu\text{V/km}$ . The decrease of the magnitude of the resonance response is accompanied by a considerably wider range of phase angle variation,  $-60^\circ$  to  $-120^\circ$ . Fluids may be present in this stratum and may be associated with the minor leakage of hydrocarbon fluids which filled pore spaces or defective parts of the stratum. The stratum which extends from 33 Hz down to 5 Hz is characterized by an increase in the magnitude of resonance response, averages at  $260 \mu\text{V/km}$ . Phase angle variation is narrow. This section of the log is interpreted as a dry stratum. The stratum which extends from 5 Hz down to 0.8 Hz shows a drop in the magnitude of resonance response to  $130 \mu\text{V/km}$ . Between 5 Hz and 1.8 Hz, variation of phase angle appear to be narrow but becomes wider from 1.8 Hz to 0.3 Hz. The considerable increases in the magnitude of resonance response to  $440 \mu\text{V/km}$  take place between 0.8 Hz and 0.6 Hz. These increases are accompanied by a wide range phase angle variation,  $-160^\circ$  to  $+180^\circ$ . At this frequency, the equivalent depth where oil is found is 710 m and the thickness of the oil-bearing stratum is approximately 110 m. However, since the contrast of the magnitude of the resonance response is considered weak, the reservoir is categorized as low saturation. The section of the log between 1.8 Hz and 0.8 Hz shows a wide range phase angle variation,  $-170^\circ$  to  $+180^\circ$  and exhibits low magnitude resonance response which averages at  $130 \mu\text{V/km}$ . This suggests that parts of the seal rocks at this depth range may be defective. Oil to water interface was found at 0.6 Hz, at which the magnitude of resonance response drops to  $220 \mu\text{V/km}$  and the phase angle variation remains wide,  $-170^\circ$  to  $+170^\circ$ . The skin-depth analysis for constructing the resistivity and depth logs of Mahatma-1 well is shown in Figs 3c3 and 3c4.



**Figure 3a.** ETR-Log of the Mahatma-1 well, NS profile. Sajau Area, North Kalimantan.



**Figure 3b.** ETR-Log of the Mahatma-1 well, WE profile. Sajau Area, North Kalimantan.



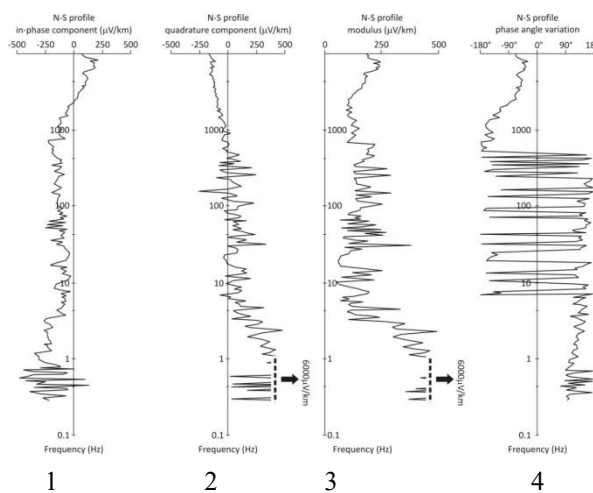
**Figure 3c.** The skin-depth analysis of ETR-Log of the Mahatma-1 well, Sajau Area, North Kalimantan.

### 3.2. Sumur Belanda-3

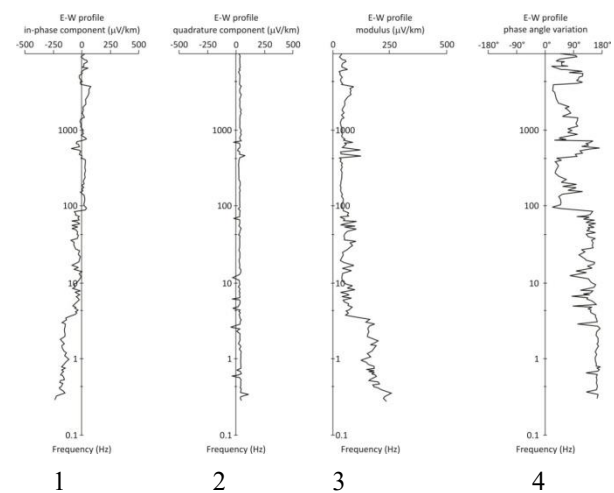
The ETR-Log acquired at Sumur Belanda-3 is shown in Figure 4, the NS profile in Figure 4a and the WE profile in Figure 4b. On the NS profile, Figure 4a1 shows the in-phase components, Figure 4a2 shows the quadrature-phase components, Figure 4a3 shows the modulus and Figure 4a4 shows the phase angle variation of the telluric energy along the logs. Similarly, on the WE profile, Figure 4b1 depicts the in-phase components, Figure 4b2 depicts the quadrature phase components, Figure 4b3 depicts the modulus and Figure 4b4 depicts the phase angle variation of the telluric energy along the logs. The extension of the scales in Figures 4a and 4b are necessary as a very high contrast of resonance response at the lower frequency band diminishes the readability of the logs at the upper bands. Figure 4c demonstrates the construction of resistivity and depth logs based on the skin-depth principles. Figure 4c1 depicts the modulus of the resonance response of the NS profile (dashed line) along with the outline of the interpreted intensity of the telluric energy (solid line) and the corresponding values of the resistivity. Figure 4c2 shows the variation of phase angle of the telluric vectors along the log. Figure 4c3 demonstrates the drawings of the resistivity profile (solid line) guided by the resistivity constraint (dashed line) on the skin-depth chart to construct the logs of resistivity and depth (Figure 4c4). The resistivity constraint of 1.6  $\Omega\text{m}$  obtained at Mahatma-1 well was used for constructing the resistivity and depth logs of Sumur Belanda-3.

The top-most stratum of the ETR-Log of the Sumur Belanda-3 (Figure 4a1) is characterized by a low level magnitude resonance response, 205  $\mu\text{V/km}$ , extending from 10.000 Hz to 3300 Hz. Phase angle variation is narrow, averages at  $-50^\circ$ . This section of the log is interpreted as a dry stratum. The lower stratum extends from 3300 Hz down to 550 Hz. Phase angle varies very narrowly, averages at  $20^\circ$  and magnitude of resonance response to 125  $\mu\text{V/km}$ . This section of the log is interpreted as a dry rock layer. The stratum which extends from 550 Hz down to 33 Hz is characterized by a weak increase in magnitude of resonance response, 180  $\mu\text{V/km}$ . Phase angle varies widely from  $-180^\circ$  to  $+180^\circ$  between 550 Hz and 6.8 Hz and the magnitude of resonance response also decreases. This section of the log is interpreted as to characterize the present of high ionic activities within the rock layers, most probably resulted from the upward escape of the hydrocarbon fluids. The very wide range of phase angle variation and the low magnitude of resonance response continue down to 6.8 Hz. This is interpreted that, within the frequency band of 550 Hz to 6.8 Hz, equivalent to a depth range between

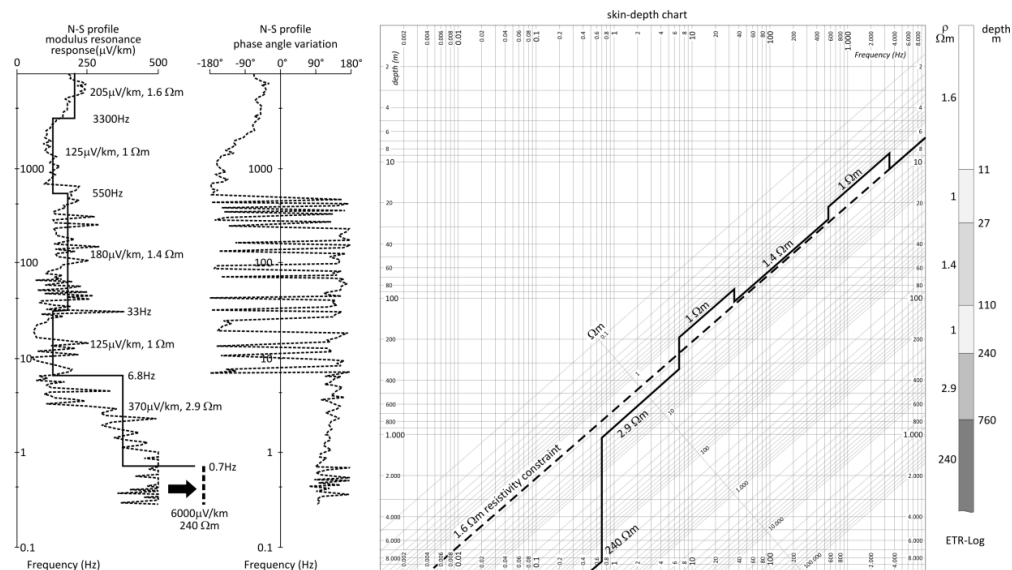
27 m and 240 m, the rock layers are defective. The stratum which extends from 6.8 Hz down to 0.7 Hz is characterized by another weak increases in the magnitude of the resonance response to 370  $\mu\text{V}/\text{km}$ . Phase angle variation is very narrow,  $+30^\circ$ , ionic activities are absent, because fluids are not present. This section of the log is interpreted as a dry rock layer. Further down on the log, a very high contrast of the magnitude of resonance response, registers up to 5000  $\mu\text{V}/\text{km}$  is encountered at 0.7 Hz (equivalent to a depth of 760 m). However, variation of phase angle is narrow,  $+100^\circ$  to  $+160^\circ$ . This suggests that ionic activity are very weak. This section of the log is interpreted as to represent a stratum of bearing no hydrocarbon fluids. The hydrocarbon fluids have escaped upwards and filled the pore spaces of the defected parts of the shallower rock layers as well as flooded the ground surface. Oil pools were found 10 m east of the logging station at Sumur Belanda-3. More extensive oil floods were also found further east into forest areas. The measurements at Sumur Belanda-3 were stopped at 0.3 Hz but the very high magnitude of the resonance response appears to remain, the interface to the saline-water bearing stratum was unable to be identified. The skin-depth analysis for constructing the resistivity and depth logs of the Sumur Belanda-3 is shown Figures 4c3 and 4c4.



**Figure 4a.** ETR-Log of Sumur Belanda-3 (extended scales), NS profile. Sajau Area, North Kalimantan.



**Figure 4b.** ETR-Log of Sumur Belanda-3 (extended scales), WE profile. Sajau Area, North Kalimantan.



**Figure 4c.** The skin-depth analysis of ETR-Log of Sumur Belanda-3, Sajau Area, North Kalimantan.

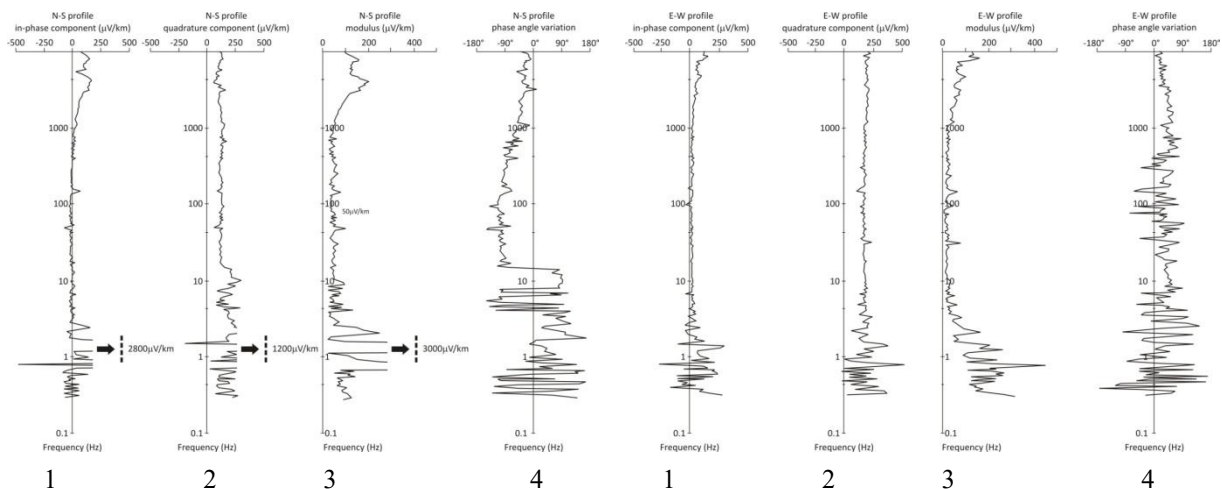
### 3.3. Seberaba-3

The ETR-Log acquired at Seberaba-3 is shown in Figure 5, the NS profile in Figure 5a and the WE profile in Figure 5b. On the NS profile, Figure 5a1 shows the in-phase components, Figure 5a2 shows the quadrature-phase components, Figure 5a3 shows the modulus and Figure 5a4 shows the phase angle variation of the telluric energy along the logs. Similarly, on the WE profile, Figure 5b1 depicts the in-phase components, Figure 5b2 depicts the quadrature phase components, Figure 5b3 depicts the modulus and Figure 5b4 depicts the phase angle variation of the telluric energy along the logs. The extension of the scales in Figures 5a and 5b are necessary as a very high contrast of resonance response at the lower frequency band diminishes the readability of the logs at the upper bands. Figure 5c demonstrates the construction of resistivity and depth logs based on the skin-depth principles.

Figure 5e1 depicts the modulus of the resonance response of the NS profile (dashed line) along with the outline of the interpreted intensity of the telluric energy (solid line) and the corresponding values of the resistivity. Figure 5e2 shows the variation of phase angle of the telluric vectors along the log. Figure 5e3 demonstrates skin-depth analysis to construct the logs of resistivity and depth (Figure 5e4). The resistivity constraint of  $1.6 \Omega\text{m}$  supplied from the Mahatma-1 well was used for constructing the resistivity and depth logs of the Seberaba-3.

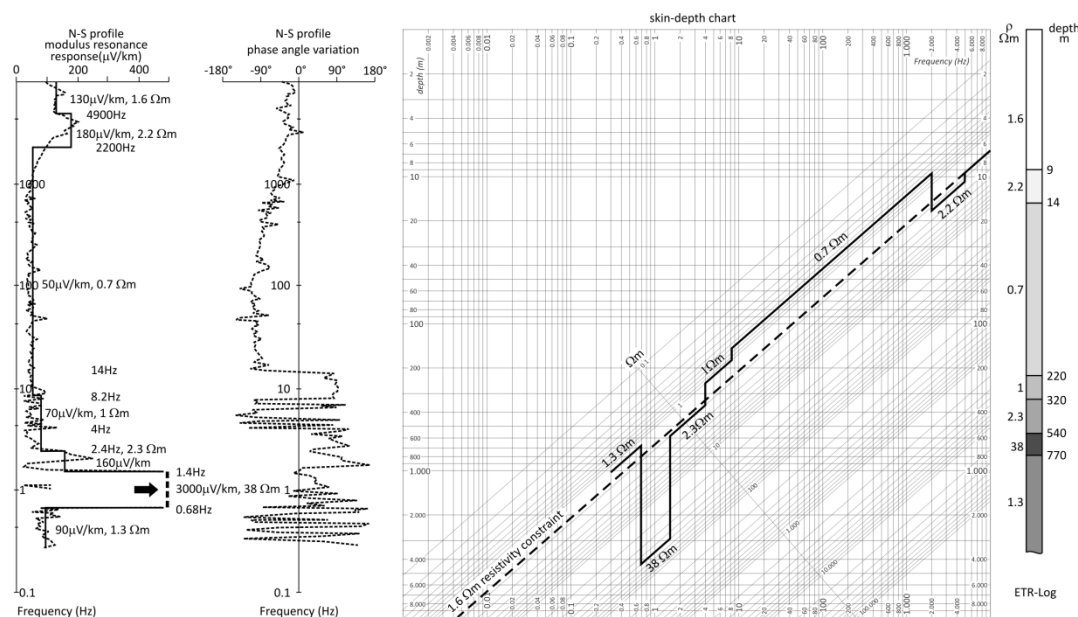
The top-most stratum of the ETR-Log of Seberaba-3 (Figure 5e1) is characterized by a low level magnitude of resonance response of  $130 \mu\text{V/km}$ , extending from  $10.000 \text{ Hz}$  to  $4900 \text{ Hz}$ . This stratum is also characterized by a narrow range of phase angle variation, from  $-20^\circ$  to  $-50^\circ$ . This section of the log is interpreted as a dry rock layer. The lower stratum extends from  $4900 \text{ Hz}$  to  $2200 \text{ Hz}$ . Phase angle varies very narrowly, averages at  $20^\circ$  and the magnitude of resonance response weakly increases to  $180 \mu\text{V/km}$ . This section of the log is interpreted as a dry layer. The stratum which extends from  $2200 \text{ Hz}$  to  $14 \text{ Hz}$  is characterized by a lower level of magnitude of resonance response,  $50 \mu\text{V/km}$ . Phase angle variation is narrow,  $-10^\circ$  to  $-130^\circ$ . It is interpreted as a dry rock layer. At  $14 \text{ Hz}$ , an abrupt transition of phase angle from  $-120^\circ$  to  $+80^\circ$  takes place and continues steadily at  $+80^\circ$  down to  $8.2 \text{ Hz}$ , the magnitude of resonance response remains low. This part of the log is interpreted a dry rock layer. The abrupt transition of the phase angle at  $14 \text{ Hz}$  may have resulted from ionic activities within the fluid-filled defected parts of the rock layer. Between  $14 \text{ Hz}$  and  $8.2 \text{ Hz}$  phase angle varies narrowly, averages at  $+80^\circ$  while the magnitude of the resonance response remains low,  $50 \mu\text{V/km}$ . This section of the log is interpreted as a dry rock layer. The stratum which extends from  $8.2 \text{ Hz}$  down to  $2.4 \text{ Hz}$  shows a weak increase in the magnitude of the resonance response to  $70 \mu\text{V/km}$ . Between  $8.2 \text{ Hz}$  and  $4 \text{ Hz}$ , phase angle varies very widely from  $-160^\circ$  to  $+100^\circ$  and the magnitude of resonance response remains very low. This part of the log is interpreted as stratum or part of a stratum with a high ionic activities which results from fluids contents within the rock layer. However, the low level magnitude of resonance response suggest that the fluids may represent the upward escaping hydrocarbons, filling the cavities of defective parts of the rock layer. The stratum which extends from  $4 \text{ Hz}$  down to  $2.4 \text{ Hz}$  shows a narrower range phase angle variation, despite the resonance response remains at  $70 \mu\text{V/km}$ . The frequency band between  $2.4 \text{ Hz}$  and  $1.4 \text{ Hz}$  shows a weak increase in the magnitude of the resonance response to  $160 \mu\text{V/km}$  and exhibits a fairly narrow range of phase angle variation. This part of the section of the log is interpreted as a dry rock layer. The stratum which extends from  $1.4 \text{ Hz}$  and  $0.68 \text{ Hz}$  shows a very high magnitude of resonance response,  $3000 \mu\text{V/km}$  but, phase angle variation remains at a fairly narrow range, from  $-20^\circ$  to  $+130^\circ$ . This section of the log is interpreted as to represent an almost dried stratum. Hydrocarbon may be present but the saturation is extremely low. The interface to the saline-water bearing stratum is identified with the drop of the magnitude of the resonance response to  $90 \mu\text{V/km}$  at  $0.68 \text{ Hz}$ . Phase angle varies very widely from  $-130^\circ$  to  $175^\circ$ . The skin-depth analysis for constructing the resistivity and depth logs of the Seberaba-3 is demonstrated Figures 5e3 and 5e4.





**Figure 5a.** ETR-Log of Seberaba-3(extended scales), NS profile. Sajau Area, North Kalimantan.

**Figure 5b.** ETR-Log of Seberaba-3(extended scales), WE profile. Sajau Area, North Kalimantan.



**Figure 5c.** The skin-depth analysis of ETR-Log of Seberaba-3, Sajau Area, North Kalimantan.

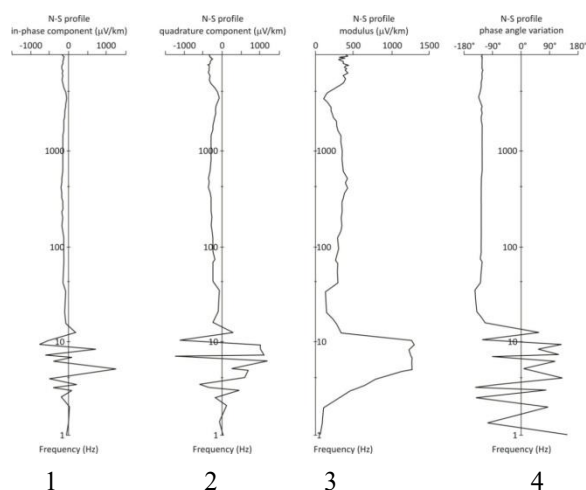
### 3.4. B-09X

The ETR-Log acquired at B-09X is shown in Figure 6, the NS profile in Figure 6a and the WE profile in Figure 6b. On the NS profile, Figure 6a1 shows the in-phase components of the resonance response, Figure 6a2 shows the quadrature-phase components, Figure 6a3 shows the modulus and Figure 6a4 shows the phase angle variation of the telluric energy along the logs. Similarly, on the WE profile, Figure 6b1 depicts the in-phase components of the resonance response, Figure 6b2 depicts the quadrature-phase components, Figure 6b3 depicts the modulus and Figure 6b4 depicts the phase angle variation of the telluric energy along the logs. Figure 6c demonstrate the construction of the resistivity and depth logs using the skin-depth principles. As a result of the unavailability of the depth constraint for the skin-depth analysis of the ETR-Log in Tanjung Area, the analysis was carried out by making

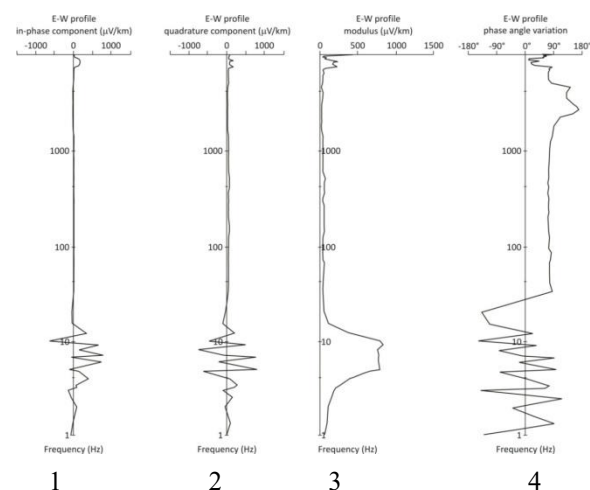


use of an arbitrary value of resistivity constraint of  $5 \Omega\text{m}$  and explore the depth effects which results from the assumption, and subsequently compared to the depth and resistivity constraints (710 m and  $1.6 \Omega\text{m}$ ) obtained at Mahatma-1 well in Sajau Area. This effort was put forward in order to show the ambiguity in determining the depth when firm constraints were unavailable. The ambiguity in determining depth as well as thickness could be circumvented by providing adequate calibration for the validation of the results of the analysis. In this manner, the optimal use of ETR-Logger can be achieved.

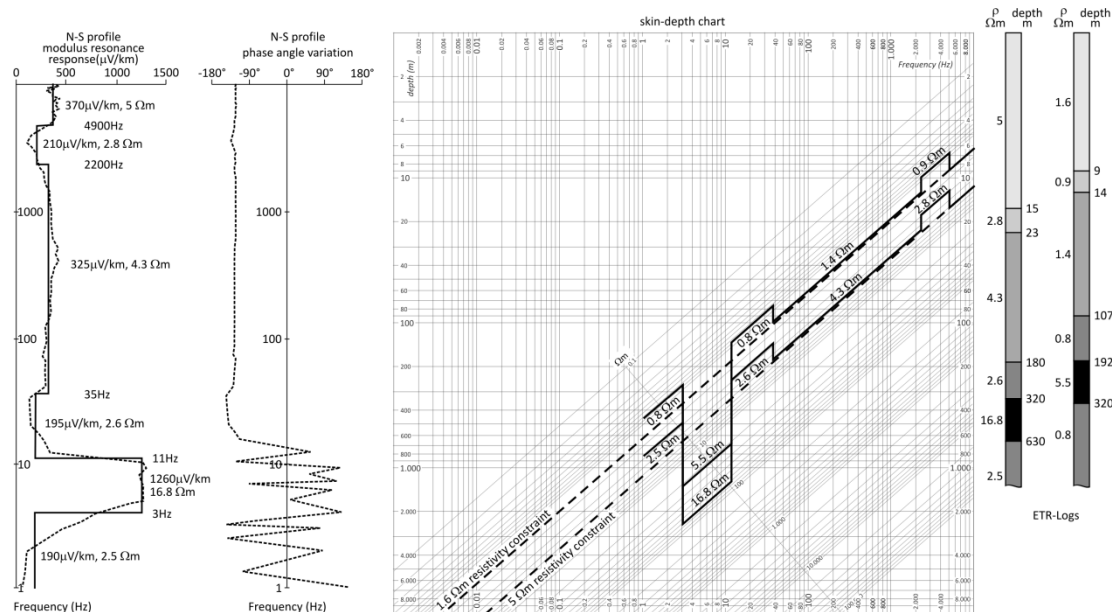
The top-most stratum of the ETR-Log of B-09X (Figure 6c) is characterized by a low level of telluric resonance response of  $370 \mu\text{V/km}$ , from 10.000 Hz to 4900 Hz. The phase angles are very steady at  $-125^\circ$  and continues unchanged down to 35 Hz. The section of the log between 10.000 Hz and 4900 Hz is interpreted as a dry rock layer. The lower stratum from 4900 Hz to 2200 Hz shows a drop of the magnitude of resonance response to  $210 \mu\text{V/km}$ . Phase angle vary narrowly, from  $-120^\circ$  to  $-135^\circ$ . This may represent a weak ionic activities which results from the circulation of a near-surface ground water. The lower stratum from 2200 Hz to 35 Hz shows a weak increase of the resonance response to  $325 \mu\text{V/km}$ . Along this frequency band, the phase angle is almost constant at  $-120^\circ$ . This section of the log is interpreted as a dry rock layer. Between 35 Hz and 11 Hz, a drop in the magnitude of resonance response to  $195 \mu\text{V/km}$  is accompanied by a minor change in the phase angle to  $-145^\circ$ . This section of the log is interpreted as a dry rock layer. A high magnitude of resonance response which is also accompanied by a very wide range of phase angle variation takes place within the frequency band of 11 Hz to 3 Hz. The magnitude of resonance response registers up to  $1260 \mu\text{V/km}$  and the phase angle varies from  $-160^\circ$  to  $+160^\circ$ , ionic activities which indicate the present of fluids are very high. This section of the log is interpreted as to represent hydrocarbon-bearing stratum. Using an arbitrary value of resistivity constraint of  $5 \Omega\text{m}$ , the equivalent depth to the top of the reservoir is 340 m and the thickness of the stratum is 310 m (Figure 6c). Using the resistivity constraint of  $1.6 \Omega\text{m}$  obtained at Mahatma-1 well, the top of the reservoir is found at 192 m, and the thickness of the stratum is 128 m (Figure 6d). The higher the values of the resistivity constraint and the lower the frequency at which a distinct contrast of the magnitude of resonance response and the wide range of phase angle variation are identified, give greater depths to the top of the reservoir. The interface to the saline-water-bearing stratum is identified at 3 Hz, at which the magnitude of the resonance response drops very steeply to  $230 \mu\text{V/km}$  and the phase angle variation remains very wide,  $-110^\circ$  and  $+145^\circ$ .



**Figure 6a.** ETR-Log of B-09X, NS profile, Tanjung Area, South Kalimantan.



**Figure 6b.** ETR-Log of B-09X, WE profile, Tanjung Area, South Kalimantan.



**Figure 6c.** Skin-depth analysis of the ETR-Log of B-09X, Tanjung Area, South Kalimantan. A resistivity constraint of 5  $\Omega\text{m}$  (lower traces) was arbitrarily selected for the construction of the resistivity and the depth logs, as depth constraints from the recognised wells in this area were unavailable. The upper traces show the skin-depth analysis using resistivity constraint 1.6  $\Omega\text{m}$  supplied from Mahatma-1 well in Sajau Area, North Kalimantan.

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