IJCSI International Journal of Computer Science Issues, Vol. 9, Issue 3, No 3, May 2012
ISSN (Online): 1694-0814
www.IJCSI.org

Relationship of Resistivity Contrast and Thickness depth of Hydrocarbon for seabed logging application

Adeel Ansari[1], Afza Bt. Shafie[2] and Abas B Md Said[3]

[1] Computer Information Systems Department, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, Tronoh, Perak, Malaysia

[2] Fundamentals and Applied Sciences Department, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, Tronoh, Perak, Malaysia

[3] Computer Information Systems Department, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, Tronoh, Perak, Malaysia

Abstract

In this paper, simulation is carried out to determine the relationship between the resistivity contrast and the thickness depth of the Hydrocarbon reservoir in seabed logging application. In order to establish this correlation, various simulation models are carried out using Computer Simulation Technology (CST) tool and the results obtained from each simulation is plotted as graphs using MATLAB. The simulations are performed, by varying individually the resistivity contrast and the thickness depth, at each seawater depth. The results from the simulations, illustrate that the resistivity contrast and the thickness depth of the Hydrocarbon have a direct relationship and that at significant values, they clearly signify the presence of Hydrocarbon under the seabed floor.

Keywords: *Sea Bed Logging; Hydrocarbon; Controlled Source Electromagnetic; resistivity; thickness; Electric Field;*

1. Introduction

In 2000 the first SBL survey was performed offshore Angola [1]. Since then, the interest in electromagnetic methods for subsurface exploration has increased. Today, six years after, electromagnetic methods are attractive for the petroleum industry as complementary tools to seismic methods, or even standalone tools, for remote sensing of the subsurface. In a controlled-source EM (CSEM) survey [2], it is necessary to interpret the measurements in such a way that a prediction of the presence of hydrocarbons in the sedimentary layers can be made. The mechanism in seabed logging is thoroughly elaborated in the following sections along with the simulation models using Computer Simulation Technology (CST) and MATLAB for graph plotting.

In this study, we focus on the relationship between the resistivity contrast and thickness depth of the hydrocarbon reservoir in seabed logging. The seawater depth is varied from 2000m to 100m and for each seawater depth, resistivity contrast and thickness is varied individually. The electric field is measured over different offsets using various simulation models and graphs.

2. Methodology and approach

A. The Sea Bed Logging Method

Sea bed logging uses active source electromagnetic (EM) sounding technique in detecting subsurface hydrocarbon. The CSEM method uses a horizontal electric dipole (HED) source to transmit low frequency (typically 0.01 – 10Hz) signals to an array of receivers that measure the electromagnetic field at the seafloor [5]. The method relies on the large resistivity contrast between hydrocarbon-saturated reservoirs, and the surrounding sedimentary layers saturated with aqueous saline fluids. Hydrocarbon reservoirs typically have a resistivity of 30-500 Ωm), whereas the resistivity of the over and underlying sediments is typically less than a few Ωm. Both the amplitude and the phase of the received signal depend on the resistivity structure beneath the seabed [3].

By studying the variation in the resistivity contrast of the Hydrocarbon layer and thickness, as the transmitting source is towed through the receiver array, the effects of the Electric field at different offsets can be determined at scales of a few tens of meters depths of several kilometers. According to [11], as depicted by Figure 1, the receivers record the EM responses as a combination of energy pathways including signal transmitted directly through seawater, reflection and refraction via the sea-water interface, refraction and reflection along the sea bed and reflection and refraction via possible high resistivity subsurface layers.

In the following sections it will be demonstrated that this resistivity contrast and thickness has a detectable influence on SBL data collected at the sea bed above the reservoir. The effect of the reservoir is detectable in SBL data at an appropriate frequency of 0.1 to 10 Hz [9]. For this simulation, the frequency is set to 0.125 Hz and the current is 1250 A at the transmitter end.

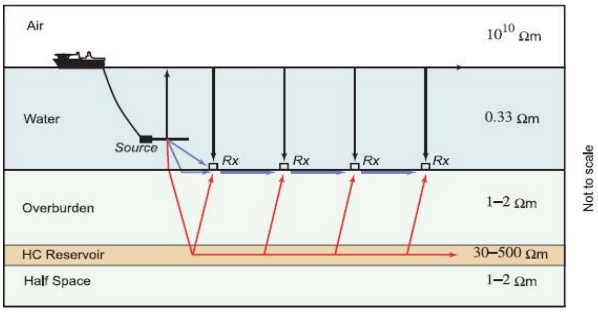

Figure 1. A Schematic diagram of Seabed logging application showing the direct waves, air waves, reflected waves and refracted waves.[11]

B. *Simulation Model 1*

The simulation model proposed here contains no Hydrocarbon reservoir, so as to determine the Electric Field at varying offset during the absence of hydrocarbon reservoir for sea water depth at 2000m, 1000m and 100m. The result obtained from this model will then be used in comparison with the graphs obtained from simulation model 2 and 3, which contains the presence of Hydrocarbon reservoirs.

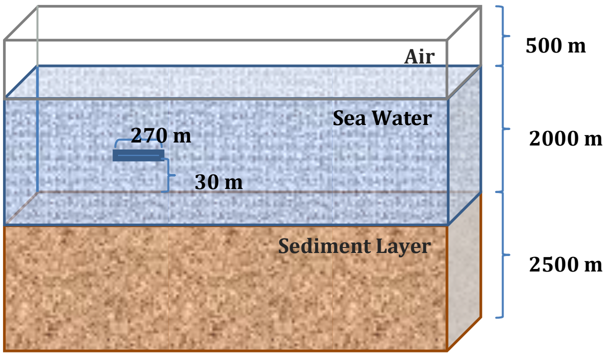

Figure 2. Simulation Model 1 showing no presence of Hydrocarbon reservoir.

C. *Simulation Model 2*

The simulation model proposed here contains a 100m thickness of Hydrocarbon Layer with a resistivity contrast of 100 Ωm. In Simulation Model 2, the resistivity contrast is varied to determine the Electric Field strength against the varying Offset for seawater depth of 2000m, 1000m and 100m.

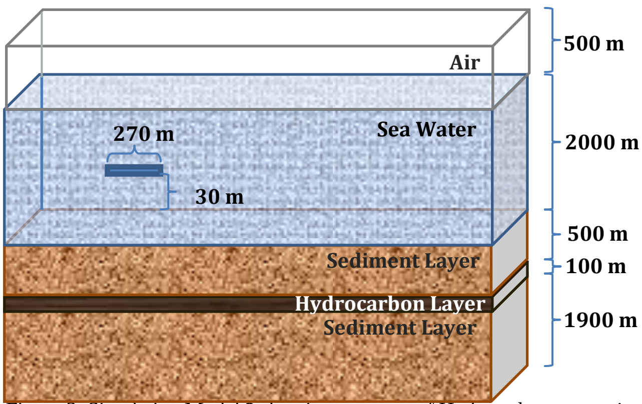

Figure 3. Simulation Model 2 showing presence of Hydrocarbon reservoir of 100m thickness, with varying resistivity contrast.

D. *Simulation Model 3*

The simulation model proposed here contains a 100m thickness of Hydrocarbon Layer with a resistivity contrast of 100 Ωm. In Simulation Model 3, the thickness is varied to determine the Electric Field strength against the varying Offset at a constant resistivity contrast of 100 Ωm for seawater depth of 2000m, 1000m and 100m.

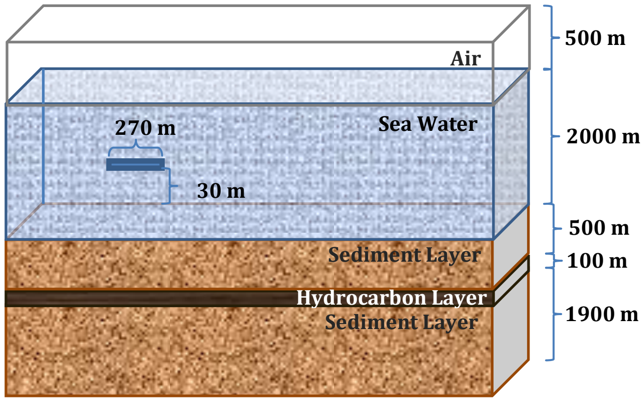

Figure 4. Simulation Model 3 showing presence of Hydrocarbon reservoir with varying thickness.

E. *Assumptions*

- The representation of the layer of Hydrocarbon reservoir is considered as a rectangular cuboid.
- For simulation 2, the resistivity contrast of the Hydrocarbon is varied with a constant thickness of 100m.
- For simulation 3, the thickness of the Hydrocarbon is varied with a constant resistivity contrast of 100 Ωm.

3. Results and discussions

In this paper, the simulations are performed using Computer Simulation Technology (CST) tool and MATLAB R2009b. The simulation results are obtained using CST whereas, the plotting of the graphs and the result estimation were developed using MATLAB programming. Assumptions are being made while conducting this simulation. The environment is assumed to be free from internal and external disturbances, no bathymetry effect, no various shapes of hydrocarbon reservoirs as well as other aspects which we may find in real world survey. This work will be improved later by taking into considerations of real sea bed environment that has many challenges and obstructions in it.
The developed simulation as in Figure 3 is used to model a plane layer of the sea bed environment, by setting the sea water (of 2000m, 1000m and 100m), sediments and size and location of the hydrocarbon trap. This model shall be used to understand the electric field variations with varying resistivity contrast of Hydrocarbon at constant thickness of 100m, as well as, the other model in Figure 4 where the thickness of the Hydrocarbon layer is varied at constant resistivity of 100Ωm. The parameters of each medium are set as follows:

Parameters	***Air***	***Sea water***	***Oil***	***Soil***
Electric Permittivity ε	1.006	80	4	30
Electrical Conductivity (S/m)	1E-11	4	0.01*	1.5
Thermal Conductivity (W/K m)	0.024	0.593	0.492	2
Density (kg/m^3)	1.293	1025	800	2600

** Electrical conductivity will vary for simulation model 2.*

This research aims to determine the nature of the relationship between the resistivity contrast and thickness of the Hydrocarbon reservoir. All the parameters are maintained; only in simulation model *2*, the resistivity contrast of the Hydrocarbon layer is decreased gradually by 20Ω-m and starting from 100Ω-m for each seawater depth. In simulation 3, the same parameters are maintained but keeping the resistivity contrast constant at 100Ω-m and varying the thickness of the Hydrocarbon layer by gradually decreasing it from 100m to 10m by 20 m decrement, for each seawater depth.

A. Results from Simulation Model 1showing no Hydrocarbon present for seawater depth of 2000m, 1000m and 100m.

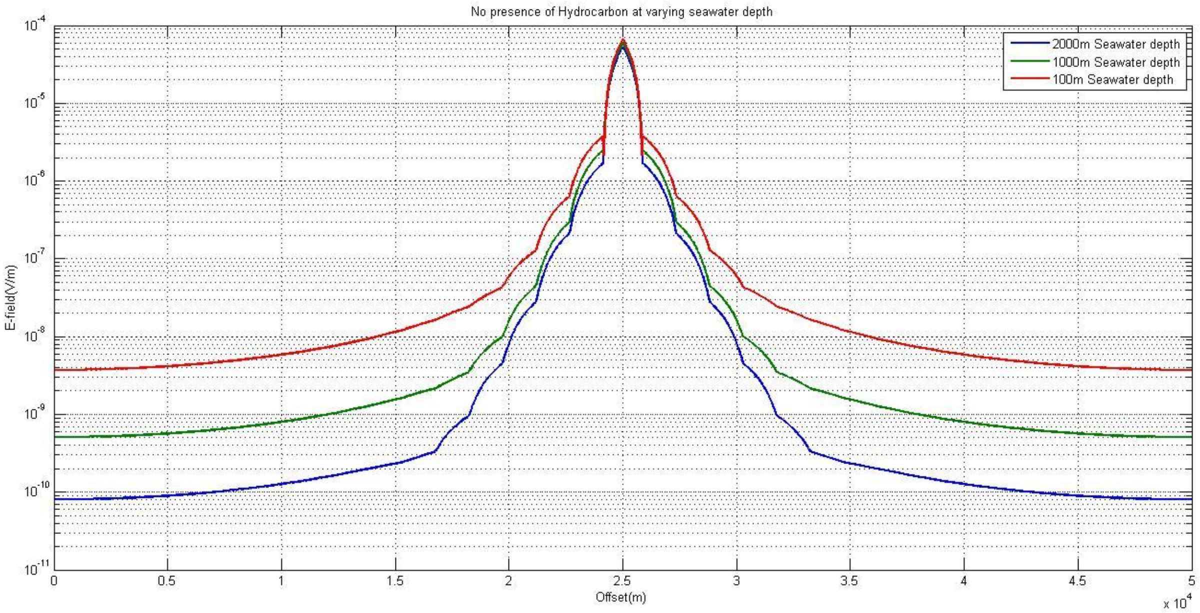

Figure 5: Electric field is plotted against the offset for sea water depth of 2000m, 1000m and 100m.

B. Results from Simulation Model 2 where the resistivity contrast is varied at constant thickness depth of 100m

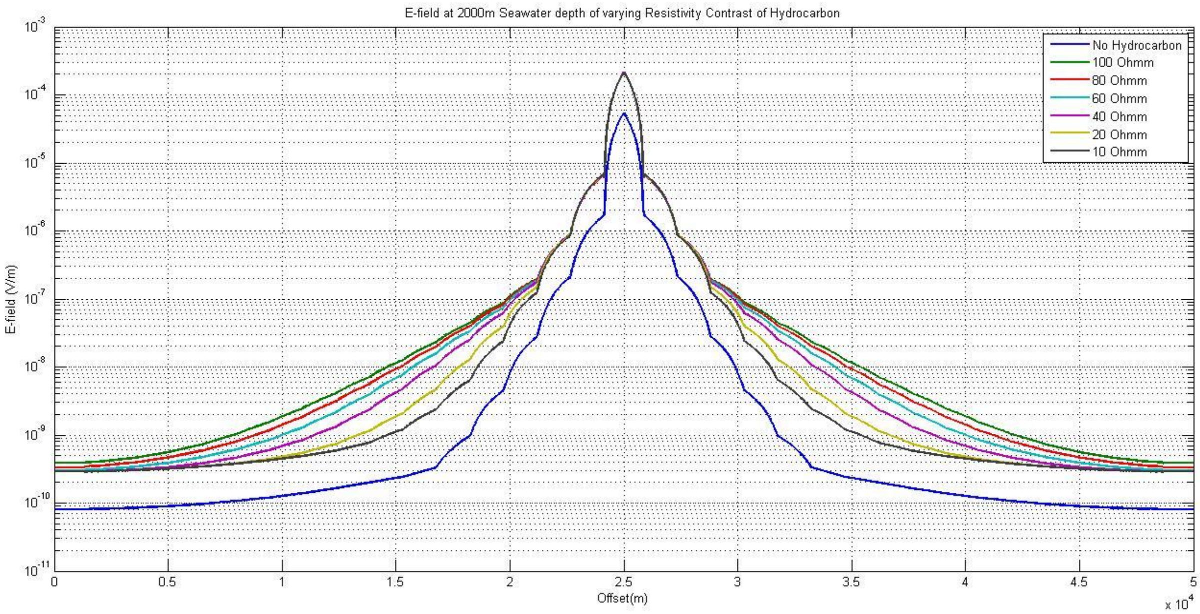

Figure 6: Electric field is plotted against the offset for sea water depth of 2000m with varying resistivity contrast of Hydrocarbon reservoir.

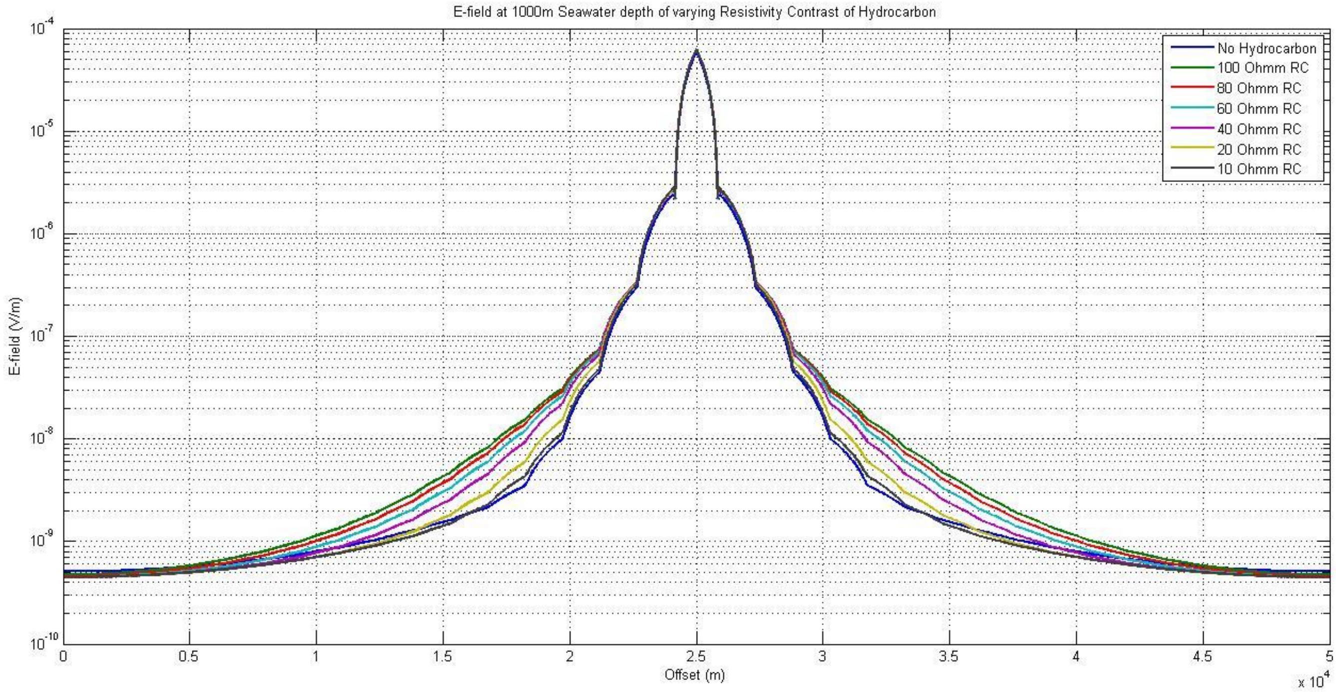

Figure 7: Electric field is plotted against the offset for sea water depth of 1000m with varying resistivity contrast of Hydrocarbon reservoir.

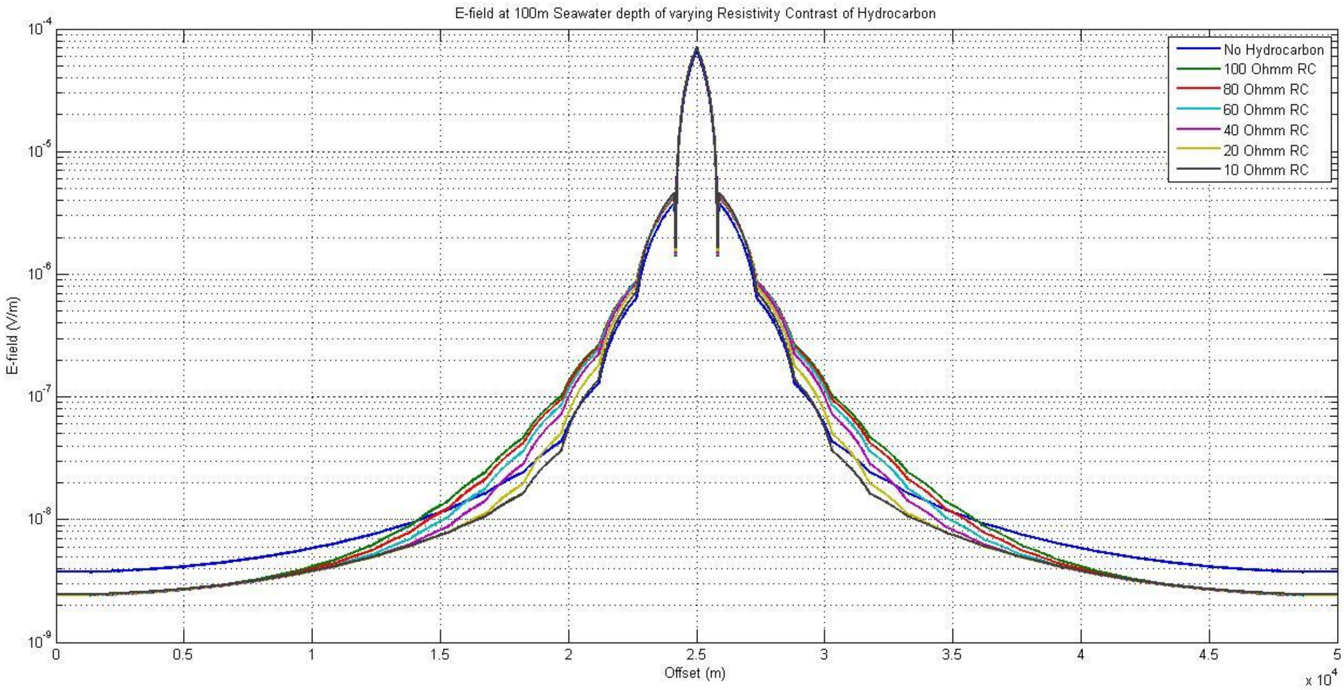

Figure 8: Electric field is plotted against the offset for sea water depth of 100m with varying resistivity contrast of Hydrocarbon reservoir.

C. Results from Simulation Model 3where the thickness depth is varied at a constant resistivity contrast of 100 Ωm

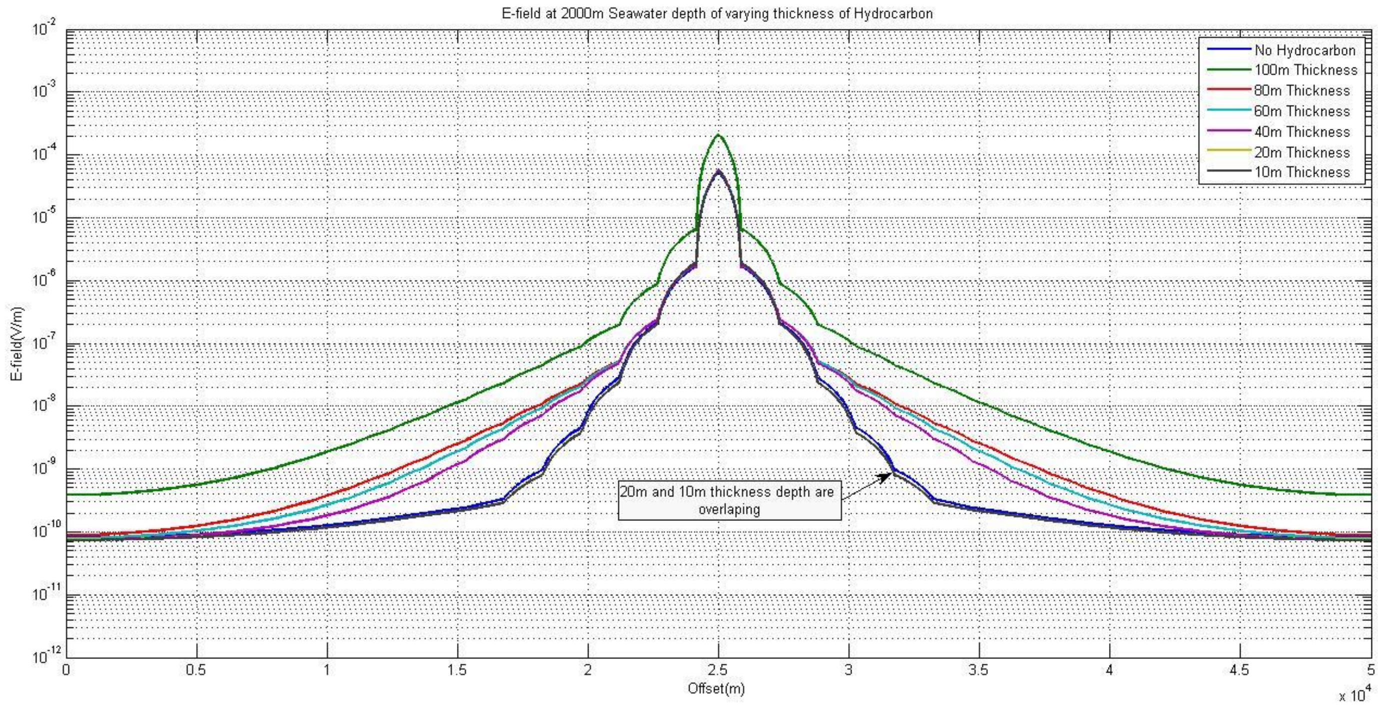

Figure 9: Electric field is plotted against the offset for sea water depth of 2000m with varying thickness depth of Hydrocarbon reservoir.

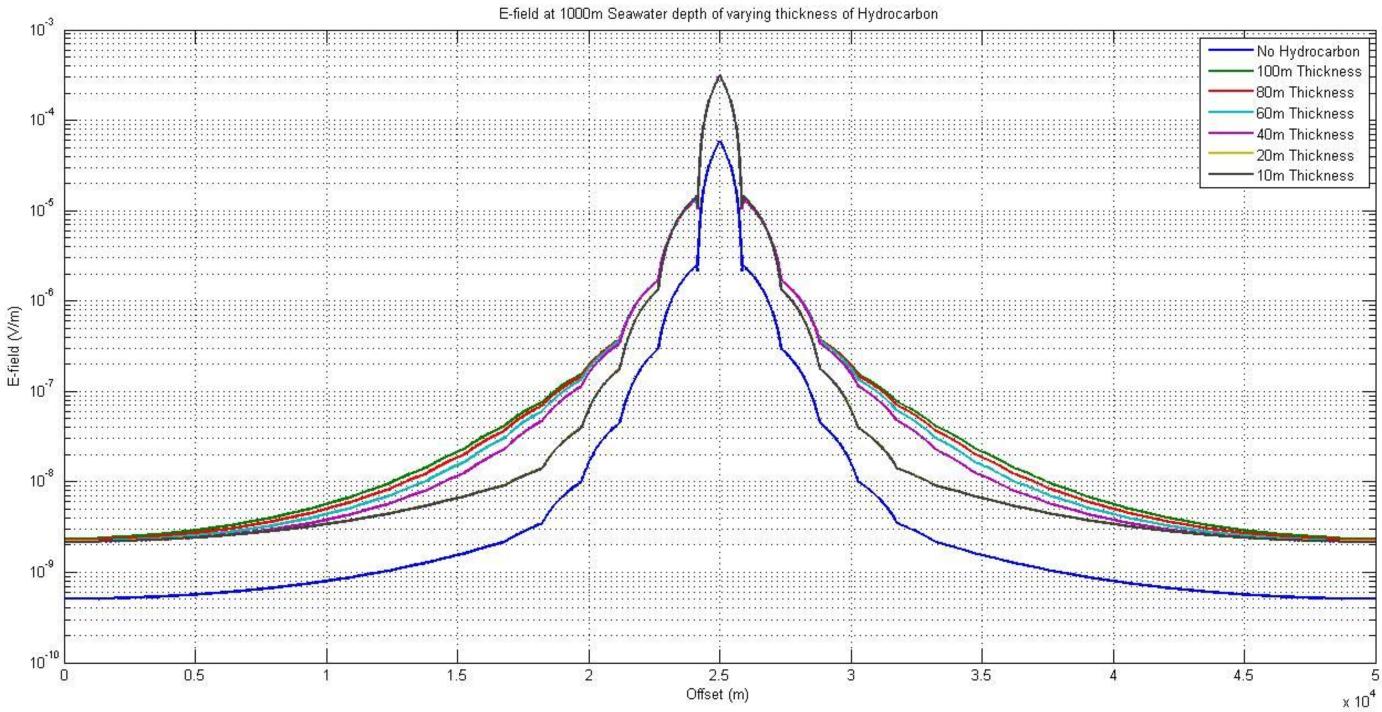

Figure 10: Electric field is plotted against the offset for sea water depth of 1000m with varying thickness depth of Hydrocarbon reservoir.

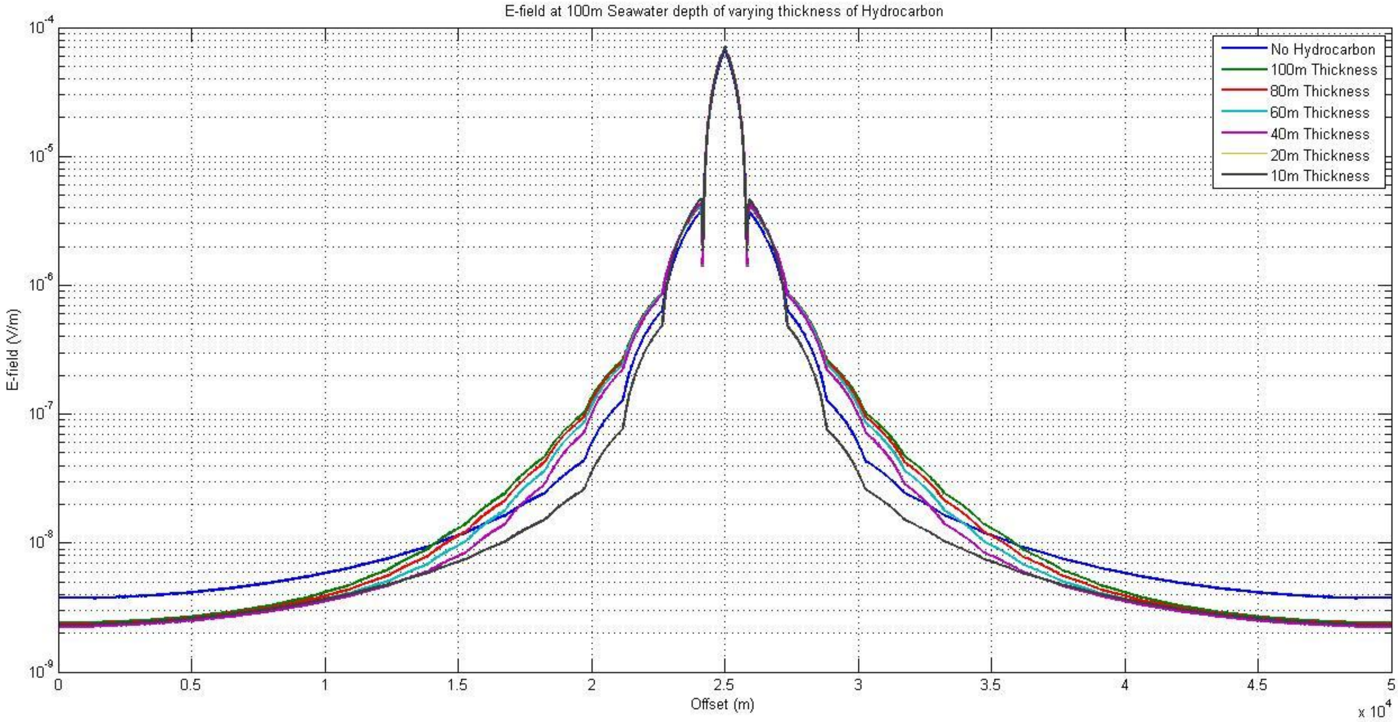

Figure 11: Electric field is plotted against the offset for sea water depth of 100m with varying thickness depth of Hydrocarbon reservoir

Figure 5 illustrates the electric field strength obtained when there is no Hydrocarbon layer present within the seabed floor for seawater depth of 2000m, 1000m and 100m. The curves in Figure 5 are used as benchmark for simulation model 2 and 3 where there is a presence of Hydrocarbon.

From Figure 6, 7 and 8, the resistivity contrast is varied for seawater depth of 2000m, 1000m and 100m. In Figure 6, the curves with varying resistivity contrast (i.e. 100Ωm, 80Ωm, 60Ωm, 40Ωm, 20Ωm and 10Ωm) are further away from the no Hydrocarbon present curve (blue). Whilst in Figure 7 and 8, the curves with varying resistivity contrast are overlapping and under the curve with no Hydrocarbon present curve (blue). This is due to the fact, that for lesser seawater depth, the direct and airwaves are dominating the receiver response and also, the fact that due to low resistivity of the Hydrocarbon, the subsurface waves are not reflected and refracted upwards towards the receiver and tend to pass through the Hydrocarbon layer, showing no presence of Hydrocarbon being present under the sea floor.

From Figure 9, 10 and 11, the thickness depth of the Hydrocarbon is varied for seawater depth of 2000m, 1000m and 100m. In Figure 9, the curves with varying thickness (i.e. 100m, 80m, 60m and 40m) are further away from the no Hydrocarbon present curve (blue). The curves of thickness depth of 20m and 10m are below the curve of no Hydrocarbon present, which implies that at thickness depth 20m or less, the subsurface waves are not reflected and refracted upwards towards the receiver. In Figure 10, all the curves with varying thickness depth are further away from the no Hydrocarbon present curve, which makes it easy to determine the presence of the Hydrocarbon reservoirs in the seabed floor. But however in Figure 11, the curves with varying thickness depth are overlapping and under the curve with no Hydrocarbon present curve (blue) significantly. This is due to the fact, that for lesser seawater depth, the direct and airwaves are dominating the receiver response and also, the fact that due to low resistivity of the Hydrocarbon, the subsurface waves are not reflected and refracted upwards towards the receiver and tend to pass through the Hydrocarbon layer, showing no presence of Hydrocarbon being present under the sea floor. Hence, Figure 11 makes it difficult to decipher the presence of Hydrocarbon reservoir under the sea floor.

D. Tables

1) Tabular results of Figure 6 showing percentage difference for sea water depth at 2000m with varying resistivity contrast at constant thickness of 100m of the Hydrocarbon reservoir.

TABLE I.

Offset	100 Ωm	80 Ωm	60 Ωm	40 Ωm	20 Ωm	10 Ωm
0	377%	315%	273%	256%	255%	255%
2,500	411%	341%	287%	259%	255%	255%
2,501	411%	341%	287%	259%	255%	255%
5,000	522%	419%	334%	273%	255%	255%
5,001	523%	420%	334%	274%	255%	255%
10,000	1380%	1012%	689%	443%	278%	254%
10,001	1385%	1016%	691%	444%	278%	254%

2) Tabular results of Figure 7 showing percentage difference for sea water depth at 1000m with varying resistivity contrast at constant thickness of 100m of the Hydrocarbon reservoir.

TABLE II.

Offset	100 Ωm	80 Ωm	60 Ωm	40 Ωm	20 Ωm	10 Ωm
0	-7%	-10%	-12%	-12%	-12%	-12%
2,500	-5%	-9%	-11%	-12%	-12%	-12%
2,501	-5%	-9%	-11%	-12%	-12%	-12%
5,000	2%	-4%	-9%	-12%	-12%	-12%
5,001	3%	-4%	-9%	-12%	-12%	-12%
10,000	42%	27%	11%	-3%	-11%	-12%
10,001	42%	27%	11%	-3%	-11%	-12%
25,000	6%	6%	6%	6%	6%	6%

3) Tabular results of Figure 8 showing percentage difference for sea water depth at 100m with varying resistivity contrast at constant thickness of 100m of the Hydrocarbon reservoir.

TABLE III.

Offset	100 Ωm	80 Ωm	60 Ωm	40 Ωm	20 Ωm	10 Ωm
0	-35%	-35%	-35%	-35%	-35%	-34%
2,500	-35%	-35%	-35%	-35%	-35%	-34%
2,501	-35%	-35%	-35%	-35%	-35%	-34%
5,000	-35%	-35%	-35%	-35%	-35%	-34%
5,001	-35%	-35%	-35%	-35%	-35%	-34%
10,000	-29%	-32%	-34%	-35%	-35%	-34%
10,001	-29%	-32%	-34%	-35%	-35%	-34%
25,000	7%	7%	7%	7%	7%	7%

4) Tabular results of Figure 9 showing percentage difference for sea water depth at 2000m with varying thickness at constant resistivity constrast of 100Ωm of the Hydrocarbon reservoir.

TABLE IV.

Offset	100m	80m	60m	40m	20m	10m
0	377%	10%	-1%	-7%	-8%	-8%
2,500	411%	17%	3%	-6%	-8%	-8%
2,501	411%	17%	3%	-6%	-8%	-8%
5,000	522%	38%	15%	-2%	-8%	-8%
5,001	523%	38%	15%	-2%	-8%	-8%
10,000	1380%	199%	112%	44%	-8%	-8%
10,001	1385%	200%	113%	44%	-8%	-8%
25,000	299%	6%	6%	6%	5%	5%

5) Tabular results of Figure 10 showing percentage difference for sea water depth at 1000m with varying thickness at constant resistivity constrast of 100Ωm of the Hydrocarbon reservoir.

TABLE V.

Offset	100m	80m	60m	40m	20m	10m
0	365%	346%	333%	325%	328%	326%
2,500	377%	354%	336%	326%	328%	326%
2,501	377%	354%	336%	326%	328%	326%
5,000	412%	378%	348%	329%	328%	326%
5,001	413%	378%	348%	329%	328%	326%
10,000	610%	530%	450%	376%	328%	326%
10,001	611%	530%	450%	376%	328%	326%
25,000	431%	431%	431%	431%	425%	425%
25,000	299%	299%	299%	299%	298%	297%

6) Tabular results of Figure 11 showing percentage difference for sea water depth at 100m with varying thickness at constant resistivity constrast of 100Ωm of the Hydrocarbon reservoir.

TABLE VI.

Offset	100m	80m	60m	40m	20m	10m
0	-35%	-37%	-38%	-40%	-37%	-37%
2,500	-35%	-37%	-38%	-40%	-37%	-37%
2,501	-35%	-37%	-38%	-40%	-37%	-37%
5,000	-35%	-37%	-38%	-40%	-37%	-37%
5,001	-35%	-37%	-38%	-40%	-37%	-37%
10,000	-29%	-33%	-37%	-39%	-37%	-37%
10,001	-29%	-33%	-37%	-39%	-37%	-37%
25,000	7%	7%	7%	7%	5%	5%

Tables I to III shows the percentage difference at certain sea water depth, i.e., 2000m, 1000m and 100m, of curves with varying resistivity contrasts to the curve of no Hydrocarbon present under the seabed floor. The thickness depth is kept constant at 100m of the Hydrocarbon reservoir, when varying resistivity contrast.

Also, Tables IV to VI shows the percentage difference at certain sea water depth, i.e., 2000m, 1000m and 100m, of curves with varying thickness depth to the curve of no Hydrocarbon present under the seabed floor. The resistivity contrast is kept constant at 100Ωm of the Hydrocarbon reservoir, when varying thickness depth.

By comparing both Table I and Table IV, it is clearly understood that the curve with a higher resistivity contrast and thickness depth, tends to have a higher percentage difference with the curve that shows no presence of Hydrocarbon deposits. As both the values of the resistivity contrast and thickness depth of the Hydrocarbon are decreased, the percentage differences of the curves also tend to decrease and come closer or overlap with the curve that shows no presence of the Hydrocarbon deposits (see Figure 6 and 9). It is also noted that for thickness depth 20m or less, the subsurface waves are no longer reflected or refracted upwards towards the receiver, therefore, allowing only the direct- and airwaves at the receiver (see Figure 9, 20m thickness or less curves are less than the curve with no Hydrocarbon deposit, hence negative percentage difference, see Table IV).

The same observations can be made for sea water depth at 1000m (from Tables II and V) and 100m (from Tables III and VI), the greater the values of the resistivity contrast and thickness depth of the Hydrocarbon, the greater is the percentage difference of the curves with that, that shows no hydrocarbon is present. Hence, the greater the values of the resistivity contrast and thickness depth of the Hydrocarbon, gives a better result to determine easily the presence of Hydrocarbon reservoir present under the seabed floor. Therefore, from the simulation results it can be considered that both the resistivity contrast and the thickness depth of the Hydrocarbon deposit have a direct relationship and the greater the values of these parameters, give a better results of determining the presence of Hydrocarbon being present within the oceanic lithosphere.

4. Conclusion

In this study, simulations were performed to attain a better understanding of the relationship between resistivity contrast and thickness of Hydrocarbon reservoir. In simulation model 2, the resistivity contrast is varied with constant thickness for seawater depth of 2000m, 1000m and 100m and in simulation model 3, the thickness depth is varied with a constant resistivity for the same seawater depth. From the simulations results, it is observed that the greater the values of the resistivity contrast and thickness depth of the Hydrocarbon reservoir, the greater are the chances of deciphering easily the presence of the Hydrocarbon present under the seabed floor, from the results that are attained. For lesser values of the resistivity contrast and thickness depth, it becomes difficult to determine the presence of the Hydrocarbon deposits under the seabed floor, due to the reason, that the subsurface waves do not get reflected and refracted upwards towards the receiver for Hydrocarbons with lesser resistivity contrast and thickness depth and tend to pass through these layers, therefore, only the airwaves and direct waves approach the receiver and are recorded. Therefore, as a conclusion both the resistivity contrast and thickness depth of the Hydrocarbon reservoir both have a direct relationship and play an important role in determining the presence of the Hydrocarbon reservoir under the oceanic lithosphere.

Acknowledgments

The authors would like to express their gratitude and appreciation to those who have contributed and facilitated towards the success of this paper and more particularly to Universiti Teknologi PETRONAS for the facilities provided to carry out the simulation work.

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Adeel Ansari is a researcher at the Universiti Teknologi PETRONAS University in Malaysia. His area of expertise are in the field of signal processing and data mining.

Afza Bt. Shafie is an Associate Professor at the Universiti Teknologi PETRONAS University in Malaysia. Her research area and expertise are in the area of Fundamental mathematics and Applied Sciences. She has a number of publications in the field of CSEM - Seabed Logging Application.

Abas B Md Said is an Associate Professor at the Universiti Technologi PETRONAS University in Malaysia. His research area and expertise are in the field of computer graphics, Networking and signal processing algorithms. He has a number of publications in the field of Computer Information Sciences.