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Transverse product effect on CSEM with double Hydrocarbon reservoir in seabed logging

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Abstract— In this paper, simulations are performed to reaffirm the relationship between the resistivity and the thickness of the Hydrocarbon reservoir by considering double layers of Hydrocarbon 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 the resistivity and thickness of the second Hydrocarbon layer at various target depths. The results obtained from the simulations, illustrate that the resistivity and the thickness of the Hydrocarbon have a direct relationship by a factor of 1 and that the electric field strength is affected by considering multiple layers of Hydrocarbons, so as to know that the electromagnetic waves transmitted reach the bottom layer of Hydrocarbon and not just only the first upper layer of the Hydrocarbon reservoir under the seabed floor.

Index Terms— 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 reaffirming the relationship between the resistivity and thickness of the hydrocarbon reservoir in seabed logging application by considering the simulation of having double layers of Hydrocarbon. Also, this simulation will also let us determine whether the electric field strength is affected by the multiplicity of Hydrocarbon layers, which will assist us in understanding the nature of the hydrocarbon layer. By the presence of variations within the electric field intensity, we can easily predict whether the CSEM sounding is reaching the multiple layers of Hydrocarbon within the oceanic lithosphere. The seawater depth is kept constant at 2000m whilst the target depth of the second layer hydrocarbon is varied from 500m to 900m and for each target depth, the resistivity and thickness is varied from 100 units to 10 units by a unit interval of 20 units. The electric field is measured over different offsets using various simulation models and graphs.

2 Methodology

2.1 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.

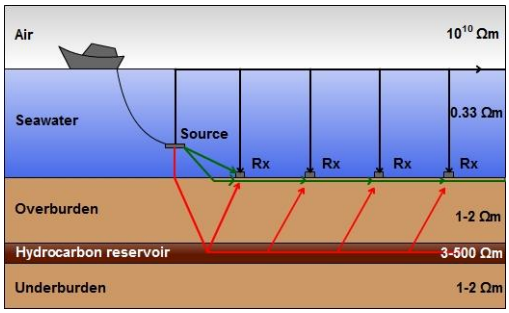

Figure 1. A Schematic diagram of Seabed logging application showing the direct waves, air waves, reflected waves and refracted waves.

2.2 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.

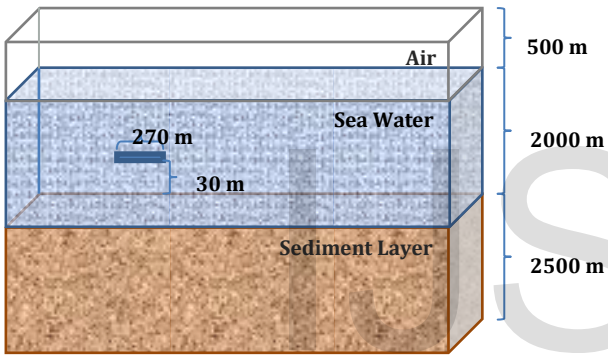

Figure 2. Simulation Model 1 showing no presence of Hydrocarbon reservoir.

2.3 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 and thickness is kept constant and the Electric Field strength against the varying Offset for seawater depth of 2000m is determined.

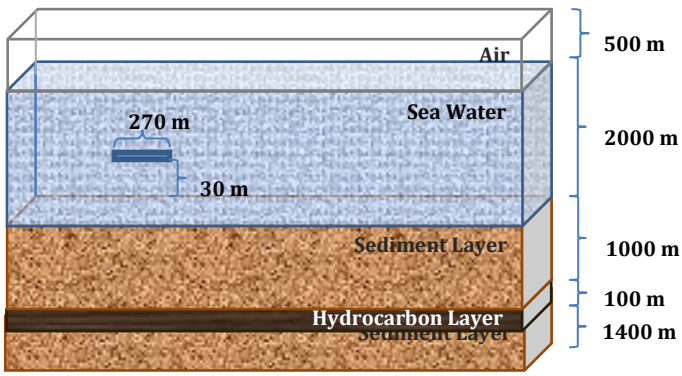

Figure 3. Simulation Model 2 showing presence of Hydrocarbon reservoir of 100m thickness, at target depth of 1000m.

2.4 Simulation Model 3

The simulation model proposed here contains another 100m thickness of Hydrocarbon Layer with a resistivity contrast of 100 Ωm and is 20km wide than compared with the bottom layered Hydrocarbon reservoir which is 50km wide. In Simulation Model 3, the thickness and resistivity is varied to determine the Electric Field strength against the varying Offset for seawater depth of 2000m. The second layer of Hydrocarbon is 500m below the seabed floor and this target depth is varied from 500m to 900m with a 100m interval.

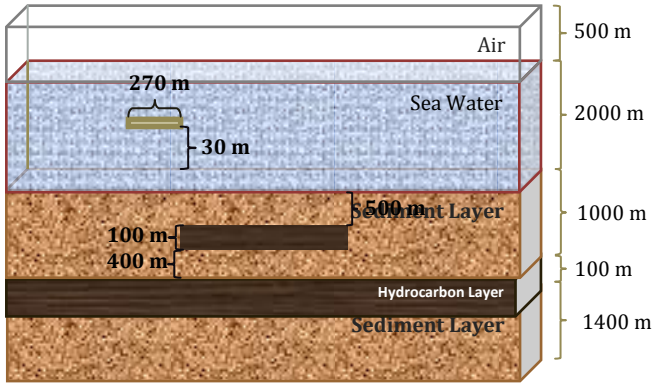

Figure 4. Simulation Model 3 showing two layers of Hydrocarbon reservoir present.

2.5 Assumptions

- The representation of the layer of Hydrocarbon reservoir is considered as a rectangular cuboid.
- For simulation 3, the resistivity of the second Hydrocarbon is varied with a constant thickness of 100m at each target depth.
- For simulation 3, the thickness of the second Hydrocarbon is varied with a constant resistivity of 100 Ωm at each target depth.

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 2,3 and 4 is used to model a plane layer of the sea bed environment, by setting the sea water (of 2000m), sediments and size and location of the hydrocarbon trap. This model shall be used to understand the electric field variations with varying resistivity of the second 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 100Ω m. 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 3.*

This research aims to determine whether the electric field measured can easily determine the presence of two Hydrocarbon reservoirs by varying the resistivity (from 100Ω m to 10Ω m) and thickness (from 100m to 10m) of the second Hydrocarbon at different target depths (500m, 600m, 700m, 800m and 900m). All the parameters are maintained; only in simulation model 3, the resistivity of the Hydrocarbon layer is decreased gradually by 20Ω-m and starting from 100Ω-m for each seawater depth. Also, the same parameters are maintained but keeping the resistivity 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.

Results from Simulation Model 1 showing no Hydrocarbon present for seawater depth of 2000m.

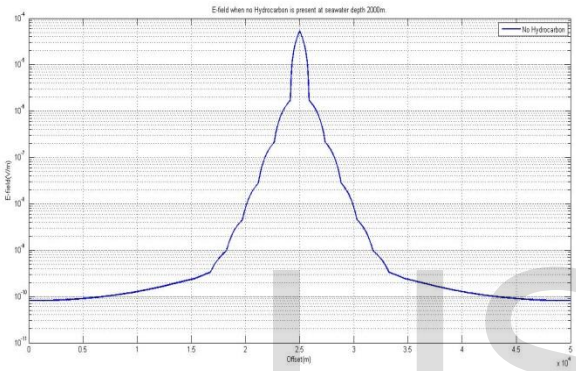

Figure 5: Electric field is plotted against the offset for sea water depth of 2000m, showing no presence of Hydrocarbon.

Results from Simulation Model 2 where Hydrocarbon reservoir is present at target depth of 1000m with 100m thickness and resistivity of 100Ω m

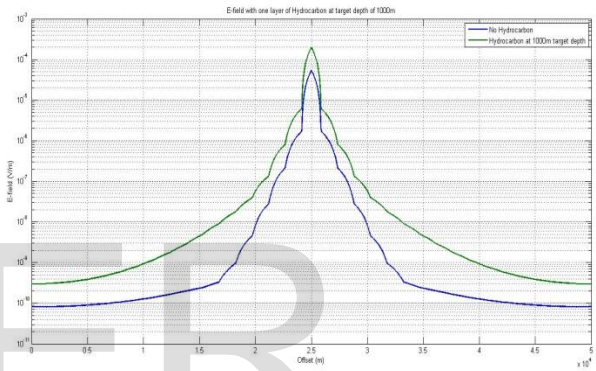

Figure 6: Electric field is plotted against the offset for sea water depth of 2000m with a Hydrocarbon layer at target depth of 1000m.

Results from Simulation Model 3 where second layer of Hydrocarbon reservoir is present at target depth of 500m with varying resistivity and thickness.

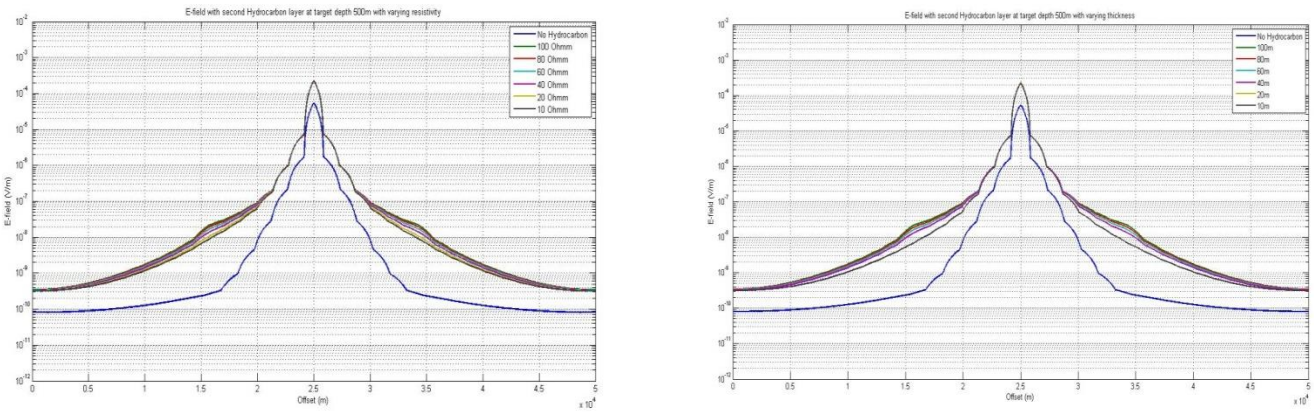

Figure 7: Electric field is plotted against the offset for sea water depth of 2000m, with varying resistivity of second layer Hydrocarbon reservoir (left) and with varying thickness (right) at 500m target depth compared with no presence of Hydrocarbon.

Results from Simulation Model 3 where second layer of Hydrocarbon reservoir is present at target depth of 700m with varying resistivity and thickness.

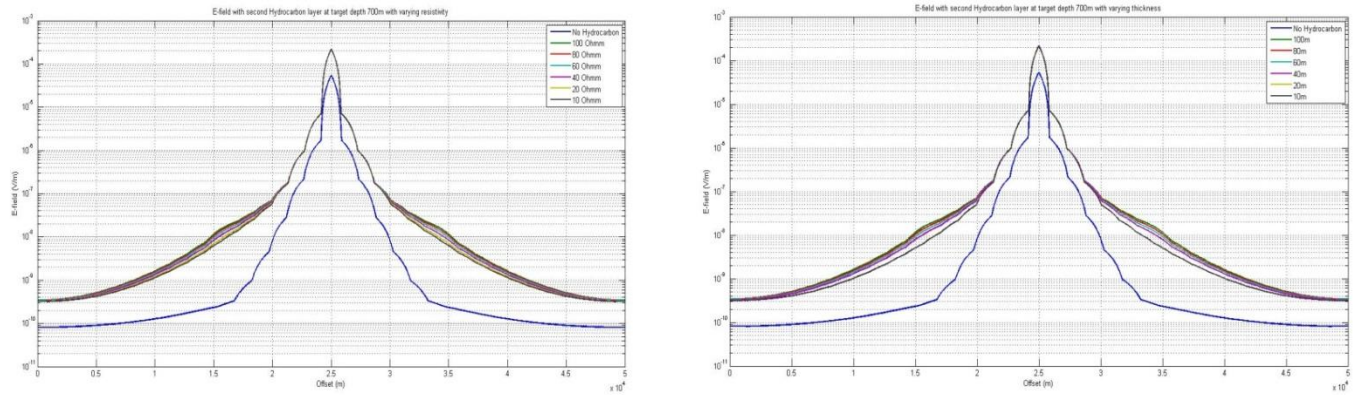

Figure 8: Electric field is plotted against the offset for sea water depth of 2000m, with varying resistivity of second layer Hydrocarbon reservoir (left) and with varying thickness (right) at 700m target depth compared with no presence of Hydrocarbon.

Results from Simulation Model 3 where second layer of Hydrocarbon reservoir is present at target depth of 900m with varying resistivity and thickness.

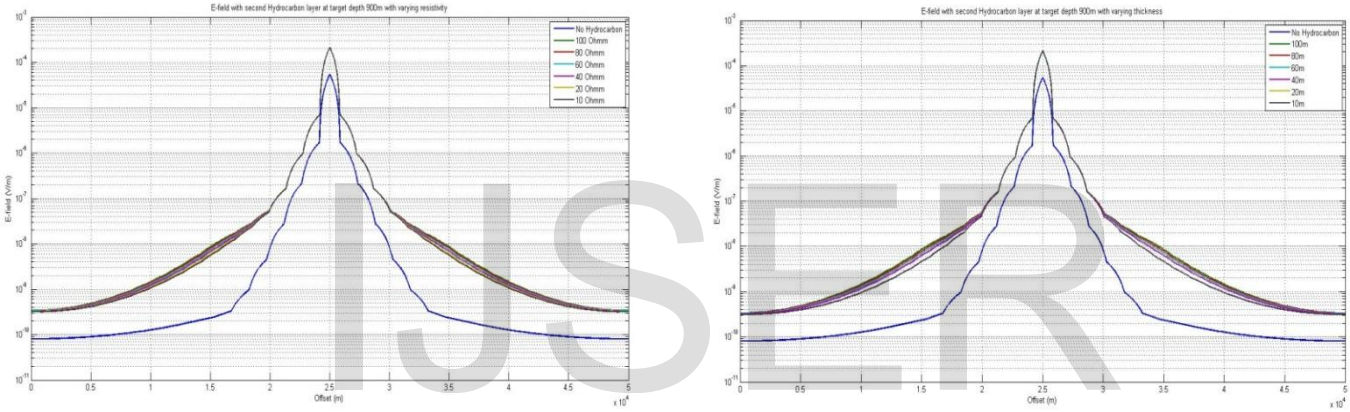

Figure 9: Electric field is plotted against the offset for sea water depth of 2000m, with varying resistivity of second layer Hydrocarbon reservoir (left) and with varying thickness (right) at 900m target depth compared with no presence of Hydrocarbon.

Graph showing second layer of Hydrocarbon reservoir is present at target depth of 900m with the bottom layer Hydrocarbon reservoir at target depth of 1000m.

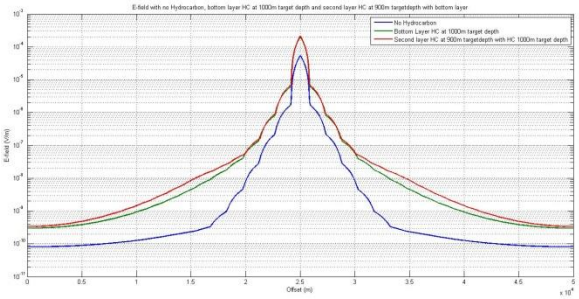

Figure 10: Electric field is plotted against the offset for bottom layer Hydrocarbon at target depth 1000m compared with second layer of Hydrocarbon at target depth 900m. There is a sudden raise in the electric field at 1.5km and a decline at 3.5km due to the presence of the second layer of Hydrocarbon reservoir.

Graph showing second layer of Hydrocarbon reservoir (20km by 20km)is present at target depth of 500m with the bottom layer Hydrocarbon reservoir at target depth of 1000m compared with curve showing only Hydrocarbon reservoir (50km by 50km) at target depth of 500m.

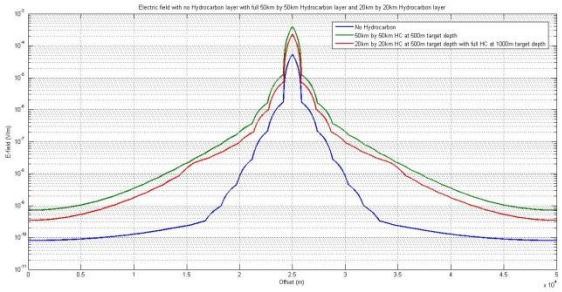

Figure 11: Electric field is plotted against the offset for no Hydrocarbon layer with bottom layer Hydrocarbon at target depth 1000m compared with second layer of Hydrocarbon at target depth 900m. There is a sudden raise in the electric field at 1.5km and a decline at 3.5km due to the presence of the second layer of Hydrocarbon reservoir.

Tables

TABLE I. SHOWS PERCENTAGE DIFFERENCE OF FIGURE 6

Offset (m)	HC layer of target depth of 1000m (50km by 50km)
0-2,500	74%
2,501-5,000	77%
5,001-10,000	86%
10,001-25,000	73%

TABLE II. SHOWS PERCENTAGE DIFFERENCE OF FIGURE 10

Offset (m)	HC of target depth of 1000m (50km by 50km)	HC of target depth 900m (20km by 20km)
0-2,500	74%	77%
2,501-5,000	77%	81%
5,001-10,000	86%	91%
10,001-25,000	73%	75%

TABLE III. SHOWS PERCENTAGE DIFFERENCE OF FIGURE 11

Offset (m)	HC layer at target depth 500m (50km by 50km)	HC layer at target depth 500m (20km by 20km)
0-2,500	89%	78%
2,501-5,000	91%	83%
5,001-10,000	96%	93%
10,001-25,000	87%	76%

Tabular results of Figure 7, 8 and 9 showing percentage differences for the two Hydrocarbon layers(bottom layer at target depth of 1000m and second layer of Hydrocarbon target depth is varied from 500m to 900m).

TABLE IV. SHOWS TARGET DEPTH OF 500M OF SECOND HYDROCARBON LAYER.

Offset (m)	100Ωm	100m	80Ωm	80m	60Ωm	60m	40Ωm	40m	20Ωm	20m	10Ωm	10m
0-2,500	78%	78%	78%	78%	77%	77%	77%	77%	76%	75%	76%	75%
2,501-5,000	83%	83%	82%	82%	82%	82%	81%	81%	80%	78%	79%	78%
5,001-10,000	93%	93%	92%	92%	92%	92%	91%	91%	90%	88%	89%	88%
10,001-25,000	76%	76%	76%	76%	76%	76%	76%	76%	76%	76%	76%	76%

TABLE V. SHOWS TARGET DEPTH OF 700M OF SECOND HYDROCARBON LAYER.

Offset (m)	100Ωm	100m	80Ωm	80m	60Ωm	60m	40Ωm	40m	20Ωm	20m	10Ωm	10m
0-2,500	78%	78%	78%	77%	77%	77%	77%	76%	76%	75%	76%	75%
2,501-5,000	82%	82%	82%	82%	81%	81%	80%	80%	79%	78%	79%	78%
5,001-10,000	92%	92%	92%	92%	91%	91%	91%	90%	90%	88%	89%	88%
10,001-25,000	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%

TABLE VI. SHOWS TARGET DEPTH OF 900M OF SECOND HYDROCARBON LAYER.

Offset (m)	100Ωm	100m	80Ωm	80m	60Ωm	60m	40Ωm	40m	20Ωm	20m	10Ωm	10m
0-2,500	77%	77%	77%	77%	77%	77%	76%	76%	76%	75%	75%	75%
2,501-5,000	81%	81%	81%	81%	80%	80%	80%	79%	79%	77%	78%	77%
5,001-10,000	91%	91%	91%	91%	90%	90%	90%	89%	89%	87%	88%	87%
10,001-25,000	75%	75%	75%	75%	75%	75%	75%	74%	75%	74%	75%	74%

Table I and Figure 6, shows the percentage difference of the bottomed layer Hydrocarbon (dimensions 50km by 50km) at target depth of 1000m (green curve) with no Hydrocarbon present (blue curve). As apparent from the graphs and tabular results there is a significant difference between the two curves, the green curve is greater in strength due to the presence of the Hydrocarbon.

Tables II and Figure 10, shows the percentage difference of the bottomed layer Hydrocarbon with the no Hydrocarbon presence. From figure 6, we can easily decipher the presence of a single Hydrocarbon layer from that which has a double layer of Hydrocarbon (one at target depth of 1000m of dimensions 50km by 50km and other at target depth of 900m with dimensions 20km by 20km). From the results it is clear that there is a sudden raise at 1.5km and at 3.5km due to the presence of the other Hydrocarbon layer at 900m target depth. This sudden raise would not be present as visible in figure 6, the curve with single layer Hydrocarbon is slightly beneath the curve with double Hydrocarbon. Hence from the results, we can easily analyze the nature of the Hydrocarbon layer, whether it is singly layered or with a double layer of varying dimensions.

Table III and Figure 11, shows the percentage differences are taken with no Hydrocarbon presence, firstly with a single layer Hydrocarbon at target depth 500m of dimensions 50km by 50km (green curve) and with double layer Hydrocarbon, with one layer at target depth of 1000m with dimensions 50km by 50km and the second is at target depth of 500m of dimensions 20km by 20km (red). From the graphs and from the tabular results, it is clearly illustrated that the green and red curves are both dissimilar and do not have any similarity, hence the electric field strength recorded for both the given scenarios are easily distinguishable and there can be no possibilities of any similarities between the two.

Table IV and Figure 7, shows the percentage differences when the second layer hydrocarbon (of dimensions 20km by 20km) is at target depth of 500m with the no hydrocarbon presence. The resistivity is varied from 100Ωm to 10Ωm, keeping the thickness constant at 100m and the same is performed by varying the thickness from 100m to 10m.

The same is performed with Table V and Figure 8, but the second layer hydrocarbon (of dimensions 20km by 20km) is at a target depth of 700m and in Table VI and Figure 9, the second

layer hydrocarbon is at target depth 900m, touching the bottom hydrocarbon layer, which is of target depth 1000m (refer to simulation model 3).

From Table IV to VI and Figure 7 to 9, it is clearly illustrated that the resistivity parameter is directly proportional to the thickness parameter of the Hydrocarbon layer. At higher values of resistivity and thickness, they are both equivalent to each other but only at 20m (of thickness) and/ or 20Ωm (of resistivity), there is a slight difference by 1%, which is considered negligible and has no significance. Therefore, the following relation can be considered:

$$R=kT$$

Where **R** is the resistivity of the Hydrocarbon, **T** is the thickness depth of the Hydrocarbon and **k** is a constant, which is 1, as from simulation experiments, these two properties are both equivalent to each other.

From figure 10 and 11, it is clearly observed that the electric field strength obtained with a single Hydrocarbon layer is different from the electric field strength obtained with double Hydrocarbon layers. Due to the presence of double layer of Hydrocarbon, the electric field strength obtained is greater than the electric field observed with single layered Hydrocarbon. At offset 1.5km and 3.5km, the presence of the second Hydrocarbon layer, causes a sudden increase in the intensity of the electric field strength and a decrease, clearly signifying, under the oceanic lithosphere, that there are multiple Hydrocarbon layers rather than just one. So therefore, from the conclusion of our simulation results and experiments, we have deduced and reaffirmed that the resistivity and thickness parameters of the Hydrocarbon are directly proportional to each other when we have single Hydrocarbon layer and/ or multiple Hydrocarbon layers. Also, another conclusion is made that electric field intensity is different for both single layered Hydrocarbon and for double layered Hydrocarbon, so via electric field strength, we may also determine the multiplicity of Hydrocarbon layers under the seabed floor.

4 Conclusion

In this study, simulations were performed to attain a better understanding of the relationship between resistivity and thickness of multiple Hydrocarbon layers within the seabed logging model. In simulation model 2, the electric field intensity of a single Hydrocarbon layer at target depth 1000m with resistivity and thickness constant at 100Ωm and 100m is observed. In simulation model 3, a second Hydrocarbon layer is introduced with dimensions 20km by 20km at target depth of 500m. The target depth of this second Hydrocarbon is varied from 500m till lastly 900m and for each target depth, the resistivity and thickness parameters are varied from 100 units till lastly 10 units. From the simulations results obtained, it is clearly evident that both the resistivity and thickness of the Hydrocarbon maintain a direct relationship with each other and this relationship is very much evident at greater values than compared with negligible values. Also, results obtained with single layered Hydrocarbon were compared with double layered Hydrocarbon and it was noted that the results obtained from both the simulations, showed different electric field strengths, hence it becomes easy to decipher the multiplicity of the Hydrocarbon layers under the seabed floor, as the double layer Hydrocarbon had a greater electric field strength intensity than with the single layer Hydrocarbon. Therefore, as conclusion it is re-affirmed that the direct relationship between resistivity and thickness is retained for even multiple layers of Hydrocarbon under the seabed and that the electric field strength is easily affected by the multiplicity of Hydrocarbon layers.

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References

[1] S. E. Johansen, H.E.F. Amundsen, T.Rosten, S. Ellingsrud, T.Eidesmo, A.H. Bhuiyan, "Subsurface Hydrocarbon Detected by Electromagnetic Sounding", Technical Article, First Break Volume 23, March 2005.

[2] L.M.MacGregor, M.Tompkins, "Imaging Hyrocarbon Reservoirs using Marine Controlled-Source Electromagnetic Sounding," in Offshore Technology Conference, 2-5May 2005, paper OTC 17163.

[3] Peter Weidelt," Guided Waves in Marine CSEM and the Adjustment Distance in MT: A Synopsis", Electromagnetic Colloquium, Czech Republic, Oct 1-5, 2007.

[4] Andreis, D., L. MacGregor," Controlled-Source Electromagnetic Sounding in Shallow Water: Principles and applications", Geophysics Journal, vol. 73, pp 21-32, 2008.

[5] Constable, S. C., and C. Weiss, 2006, Mapping thin resistors and hydrocarbons with marine EM methods: Insights from 1D modeling: Geophysics, 71, no. 2, G43–G51.

[6] EN Kong H. Westerdhal "Seabed Logging: A possible direct hydrocarbon for deepsea prospects using EM energy". Oslo : Oil & Gas Journal,2002. - May 13, 2002 edition.

[7] Constable, S., "Marine electromagnetic methods—A new tool for offshore exploration: The Leading Edge", **25**, 438–444, 2006.

[8] Eidesmo, T., Ellingsrud, S., MacGregor, L.M., Constable, S.C., Sinha, M.C., Johansen, S., Kong, F.N., Westerdahl, H., "SeaBed Logging (SBL), a new method for remote and direct identification of hydrocarbon filled layers in deepwater areas using controlled source electromagnetic sounding", First Break 20, 144–152, 2002.

[9] Ellingsrud, S., Eidesmo, T., Sinha, M.C., MacGregor, L.M., Constable, S.C., "Remote sensing of hydrocarbon layers by SeaBed Logging (SBL): results from a cruise offshore Angola", Leading Edge 20 (10), 972–982, 2002.

[10] Cox, C.S. Constable, S.C., Chave, A.D, Webb S.C., "Controlled source Electromagnetic Sounding of the oceanic Lithosphere," Nature Magazine, 1986, 320, pp 52-54.

[11] P. M. van den Berg, A. Abubakar, T. M. Habashy,"Removal of Sea Surface Related Wave¯elds from CSEM Data", Progress In Electromagnetics Research Symposium, Cambridge, USA, July 2-6, 2008.

[12] L. J. Gelius, "Multi-component Processing of Sea Bed Logging Data",PIERS Online, Vol. 2, NO. 6, 2006.

[13] Tomas Zeman, "BSS - Preprocessing Steps for Separation Improvement", CTU FEE, Dept. of Circuit Theory, May 2000.