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Investigating Deep Target Reservoirs Using MCSEM Methods

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Abstract— This paper describes a technique called Sea Bed Logging (SBL) as a tool to investigate deep sea target reservoirs. SBL is an application of marine controlled source electromagnetic (MCSEM) sounding. The basis of the approach is the use of a mobile electric dipole source and an array of electric field receivers. The transmitting dipole emits a low frequency electromagnetic signal both into the overlying water column and downwards into the seabed. The array of sea floor receivers measures both the amplitude and the phase of the received signal that depend on the resistivity structure beneath the seabed. A survey consisting of many transmitter and receiver locations can be used to determine a multidimensional model of subsea floor resistivity. A hydrocarbon reservoir can have resistivity perhaps 10 to 100 times greater. With an in-line antenna configuration the transmitted electric field enters the high resistive hydrocarbon layer under a critical angle and is guided along the layer. Electromagnetic signals constantly leak from the layer and back to the seafloor. The guiding of the electric fields significantly alters the overall pattern of current flow in the overburden layer. These capabilities are harvested in this paper in an effort to determine the depth at which hydrocarbon can be detected. A survey is done for one field one with an offset 50Km. The depth of the Hydrocarbon reserves is varied from 1000m to 3000m at intervals of 100meters. The data collected is analyzed and summarized in the preceding sections.

Index Terms— MCSEM, sediment conductivity, sea bed logging, deep sea reserves,

1 Introduction

MEARSUREMENTS of electrical resistivity beneath the seafloor have traditionally played a crucial role in hydrocarbon exploration and reservoir assessment and development. In the oil and gas industry, sub-seafloor resistivity data has, in the past, been obtained almost exclusively by wire-line logging of wells. However, there are clear advantages to developing noninvasive geophysical methods capable of providing such information. Although inevitably such methods would be unable to provide comparable vertical resolution to wire line logging, the vast saving in terms of avoiding the costs of drilling test wells into structures that do not contain economically recoverable amounts of hydrocarbon would represent a major economic advantage. Several electromagnetic methods for mapping sub-seafloor resistivity variations have been developed [1, 2]. Here we concentrate on marine controlled source electromagnetic (CSEM) sounding in the frequency domain. This technique has been successfully applied to the study of oceanic lithosphere and active spreading centers [1,3,4,5,8].In this paper we describe a technique called Sea Bed Logging (SBL), developed by Statoil [6], an application of marine CSEM sounding which can be applied to the problem of detecting and characterizing hydrocarbon bearing reservoirs in deep water areas.

The method relies on the large resistivity contrast between hydrocarbon saturated reservoirs, and the surrounding sedimentary layers [7].

Hydrocarbon reservoirs typically have a resistivity of a few tens of Ωm or higher, whereas the resistivity of the over and underlying sediments is typically less than a few Ωm [8]. It will be demonstrated that this resistivity contrast 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, and if the horizontal range from source to receiver is of the order of 2-5 times the depth of burial of the reservoir in typical situations [6].

The most crucial factors for the success of the SBL technique in practical applications related to hydrocarbon reservoirs is related to survey geometry. Subsea bed structure can be represented by horizontal layers as in figure 1. The upper layer represents sediments above a reservoir (the overburden). The middle layer, corresponding to a hydrocarbon reservoir, has resistivity perhaps 10 to–100 times greater, due to a high saturation of non-conducting hydrocarbon occupying much of the pore spaces. The deepest layer, below the reservoir, again has low resistivity due to its similarity to the overburden layer. Applying this to our model of a sub-seafloor structure containing a resistive hydrocarbon reservoir of 100m, we can deduce that the effect of the reservoir on the survey results will depend strongly on the direction of flow of the currents generated by the transmitter or the direction of the E-fields.

This study aims at investigating the e-field responses to changes in hydrocarbon reservoir depth and antenna frequency for deep water deep target scenarios. Factors affecting the propagation of EM waves in marine CSEM environment are well known from the previous literature. Considerable factors include conductivity of the media, transmission frequency, seawater depth, source-receiver orientation and skin depths.

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2 Methodology

Sea bed logging (SBL) is a technique which has been employed to scavenge for oil reservoirs in beneath the depths of seas and oceans. For decades seismic methods have been used in the exploration of onshore and offshore hydrocarbon (HC) reservoirs.

The major weakness of the seismic methods is delineating between water, gas and H.C. reserves. Marine controlled source electromagnetic (MCSEM) is a technique used in SBL which overcomes the difficulties in seismic methods. MCSEM has been handy in depicting resources beneath the surface because it utilizes the differences in electrical and magnetic responses to resistivity of materials making the earth's crust. In deep water areas the geological strata are generally dominated by shale or mud rocks with rather low resistivity. A hydrocarbon reservoir can have resistivity perhaps 10 to 100 times greater. These differences are useful in detecting and characterizing hydrocarbon bearing reservoirs in deep water areas. Challenges are faced in shallow water area where the useful EM waves are masked by the air waves refracted back to the receivers by the air above the water. Eliminating the difficult condition of air waves, in this paper we compare and analyses the strength of the refracted wave recorded by using a horizontal electric dipole (HED) in simulating deep water CSEM environment. The comparison and the analysis are on the basis of percentage differences in the Electrical Field strength between models with HC and models without HC.

The simulations were carried out to determine the depths at which deep target hydrocarbon reserves can be detected. The simulations are done using CST Studio suite 2009 covering an area of 50km by 50Km and the second model coves 100Km by 100Km. The models are of a fixed depth of 8600m, composed of layers of air, sea water, sediments (upper and lower burden) and hydrocarbon. The control is a model without hydrocarbon as shown in Figure 1. Compositions of the layers in the models are given in the sections below. Table 1 shows the parameter values for the components as used in the simulation.

Table 1: parametric values for the simulated layers

Material	Epsilon	Mue	El. Cond	Rho (kg/m^3)	Therm. Cond (W/K/m)
Air	1.006	1	1.00E-11	1.1	0.025
Hydrocarbon	4	1	0.001	800	0.492
Sea Water	80	1	4	1025	0.593
Sediment	30	1	1.5	2600	2

Table 1 shows the parametric values for the different layers which make the model.

In these simulations the depths are varied from 1000m to 3000m at intervals of 100m. The size of the model remains the same with dimensions of 100000m by 100000m length wise and width wise. The height is maintained at 8600m with the air layer configured at a fixed 500m, sea water layer is fixed in all models at 3000m. This is to ensure that the effect of air wave is not a factor in the data gathered. Studies show that air wave does not have an effect at sea water depths of more than 1000m [4]. In any given model the combined depth of the upper and lower burden adds up to 5000m except for the model 1 which has sediment depths up to 5100.

Table 2: Layer by layer configuration of the simulation models

	Model 1. No H.C.	Model 2. 1000m	Model 3. 1100m	Model 4. 1200m	-----	Model 22. 3000m
Air	500	500	500	500	-----	500
Sea Water	3000	3000	3000	3000	-----	3000
Sed. (U.B)	5100	1000	1100	1200	-----	3000
H.C.	-----	100	100	100	-----	100
Sed. (L.B.)	-----	4000	3900	3800	-----	2000
Model Thickness	8600	8600	8600	8600	-----	8600

Table 2 shows the models which are considered for the simulations. A total of 23 models are considered. The first model, model 1 is the control model which does not have a HC layer. Models 2 through 22 have a layer of HC of same thickness, 100m. The only difference is the depth below the sea floor of the HC.

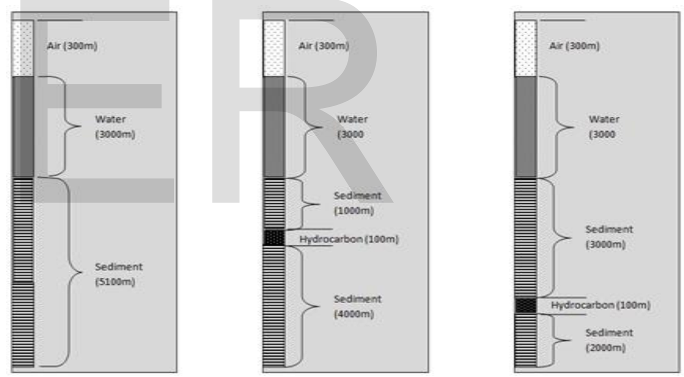

Figure 2 (a, b and c): Cross section of models 1, 2 and 22.

It can be seen that in (a) there is no HC, in (b) and (c) there are HC deposits at different depths. Figures 3A and 3B shows the 2D view of the simulation models with and without hydrocarbon and the detailed layers which makes the entire structure. These models are simulated and the results evaluated in the preceding sections.

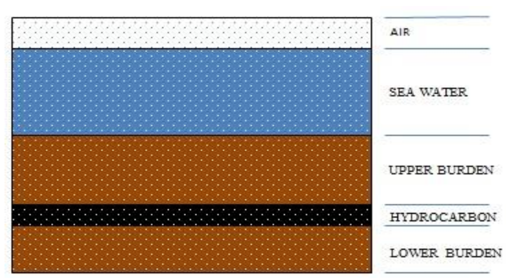

Figure 3a: 2D view of a simulation model with hydrocarbon

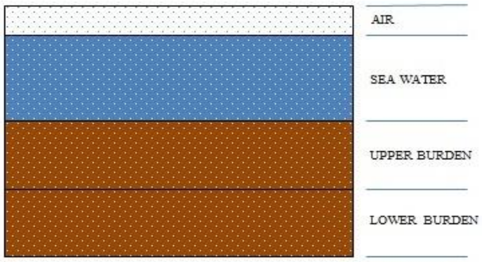

Figure 3b: 2D view of a simulation model without hydrocarbon

2 Results and Discussion

2.1 Review Stage

From the models described in the methodology section, some data have been collected on the e-field responses. This section analyses the data collected and establishes the relationship between antenna frequency and the depth of H.C. reservoirs.

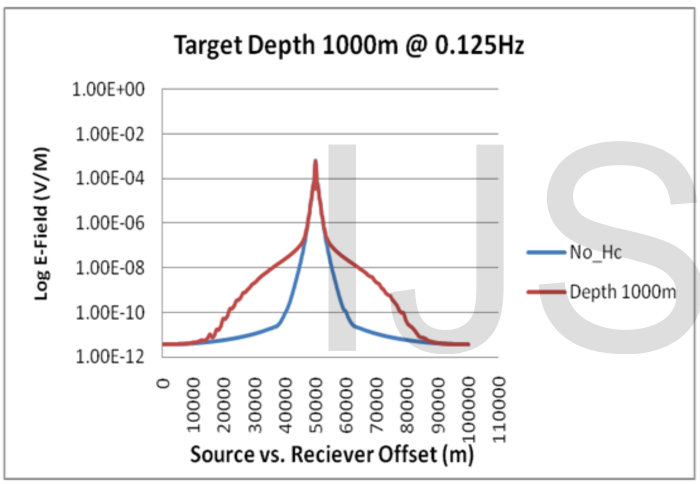

Figure 4: comparison of models with and without hydrocarbon at sea water depth of 1000m and antenna frequency of 0.125Hz.

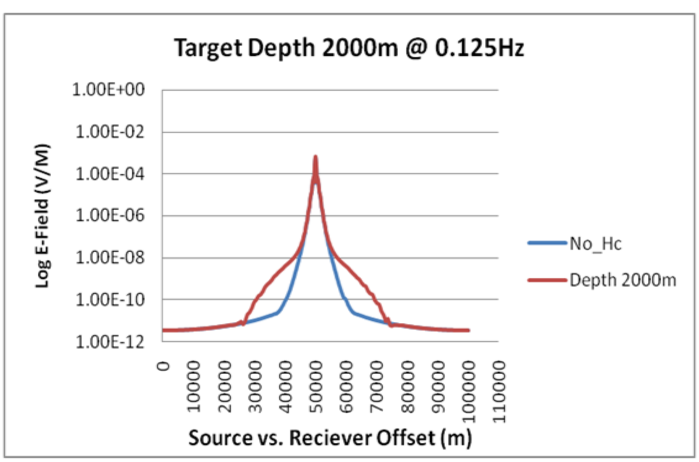

Figure 5: comparison of models with and without hydrocarbon at sea water depth of 2000m and antenna frequency of 0.125Hz.

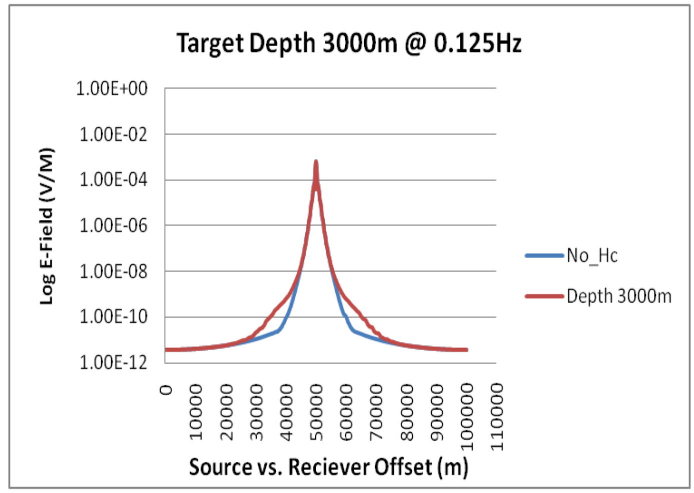

Figure 6: comparison of models with and without hydrocarbon at sea water depth of 3000m and antenna frequency of 0.125Hz

Figures 4, 5 and 6 show the changes in the behavior of the e-field component of the simulated models in CST. The depth of the sea water is varied from 1000m to 3000m at regular intervals of 100m. The frequency fed to the horizontal dipole antenna was maintained at 0.125Hz. At lower depths of 1000m, the contrast between the with and without hydrocarbon graphs as shown in figure 4 is very clear. As the depth increase to 200m a clear difference can be noted. The contrast in the two graphs gets lesser as shown in figure 5. Figure 6 shows the contrast at a depth of 3000m. This shows that the resistivity contrast diminishes with depth of the Hydrocarbon reservoir.

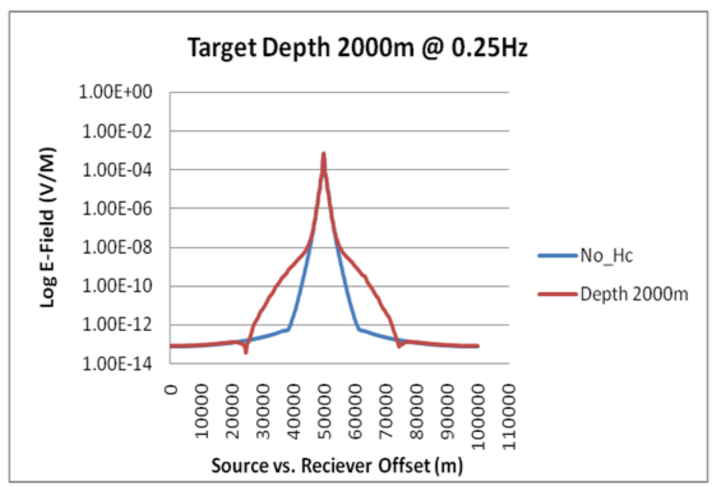

Figure 7: comparison of models with and without hydrocarbon at sea water depth of 2000m and antenna frequency of 0. 25Hz.

Figure 7 shows the contrast in the model with hydrocarbon and without hydrocarbon at a depth of 2000m but a higher frequency of 0.25Hz. Figure 8 maintains the same sea water depth but a much lesser frequency of 0.0625Hz. Comparing figures 5 and 7 and 8 shows that the depths of the HC reser-

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voir is the same but the frequencies are different. It is notable that at the far offset the resolution of the e-field values at 0.25Hz is two magnitudes less compared with at 0.125Hz and 4 magnitudes less than at 0.0625Hz .

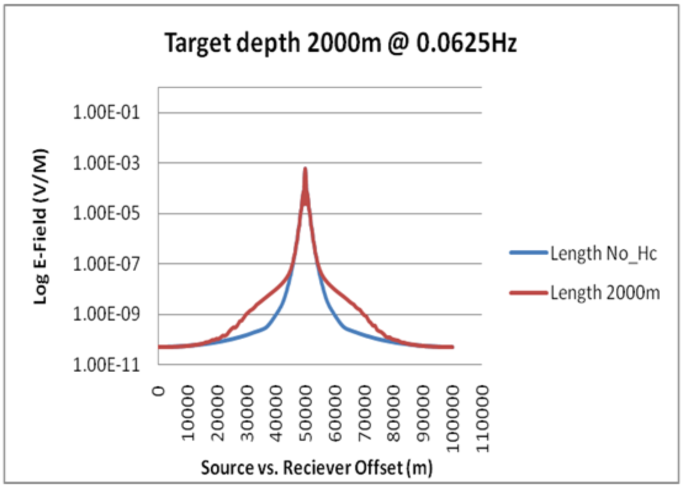

Figure 8: comparison of models with and without hydrocarbon at sea water depth of 2000m and antenna frequency of 0. 0625Hz.

This indicates that a smaller frequency will give a better resolution in the e-field contrast compared to a higher frequency although the percentage difference in the contrast at the same depths is maintained almost same.

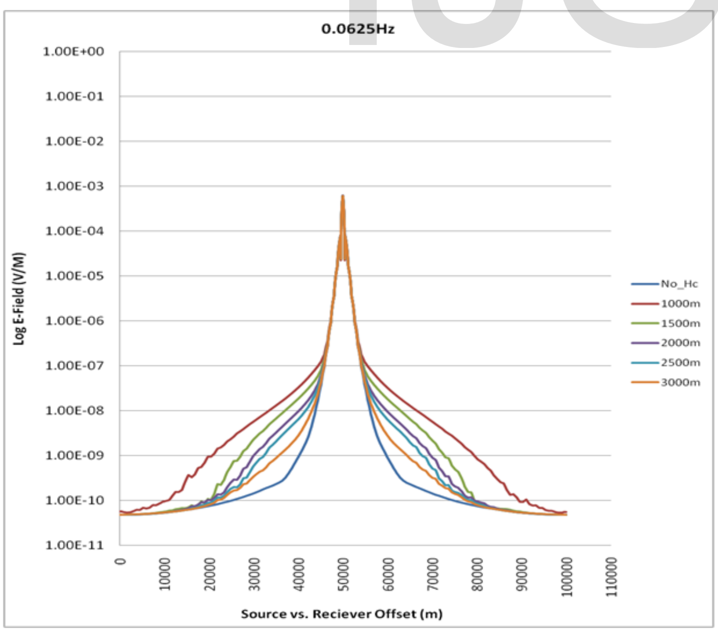

Figure 9: An illustration of e-field readings for different hydrocarbon depths of 1000m, 1500m, 2000m, 2500m and 3000m at frequency 0.0625Hz

This relationship is also clearly shown in figures 9, 10 and 11. The e-field resolution at the furthest offset, i.e. 50000m at a frequency of 0.0625Hz is 1.0E-10 while at 0.125Hz it is 1.0E-11and at 0.25Hz it is 1.0E-13. A drop in resolution of 2 magnitudes with a step size of $1/2^n$ for the frequency is observed.

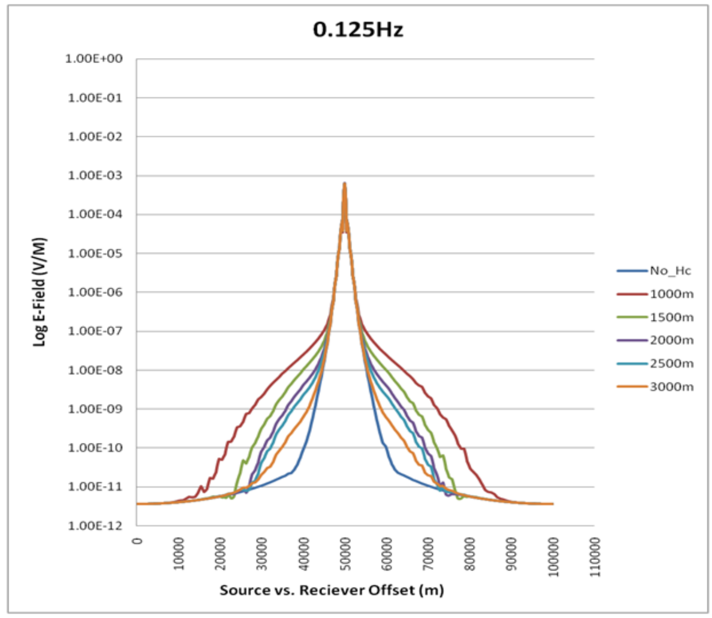

Figure 10: An illustration of e-field readings for different hydrocarbon depths of 1000m, 1500m, 2000m, 2500m and 3000m at frequency 0.125Hz

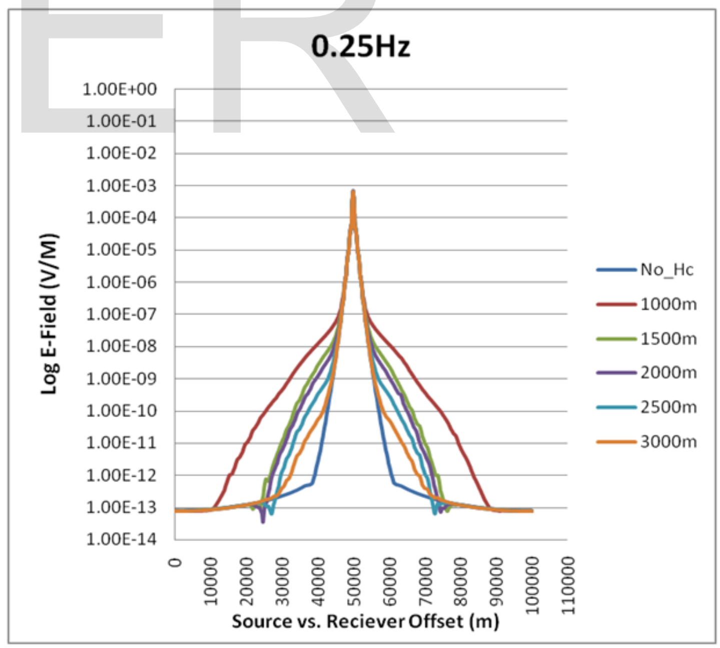

Figure 11: An illustration of e-field readings for different hydrocarbon depths of 1000m, 1500m, 2000m, 2500m and 3000m at frequency 0.25Hz.

There is a relationship which can be established between the depth below sea bed if a reservoir and the antenna frequency. Four frequencies were used in the simulations for this work which are 1Hz, 0.25Hz, 0.125Hz and 0.0125Hz. The relation is defined by the graph in Figure 12.

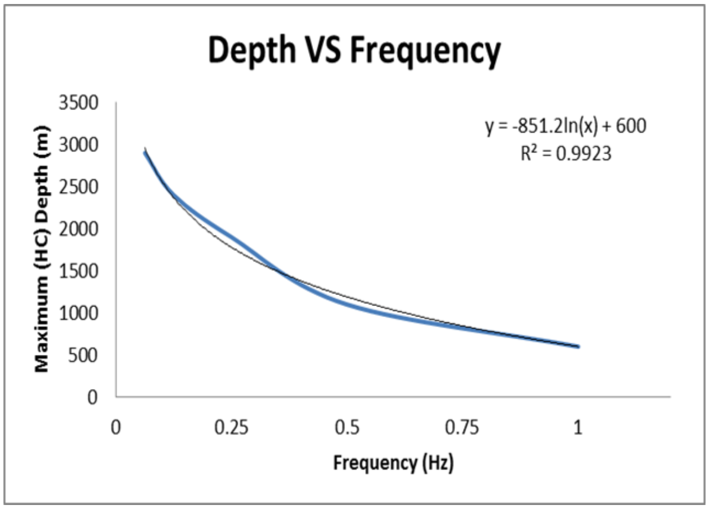

Figure 12: relationship between hydrocarbon reservoir depth and frequency.

This relationship is best described by the equation

$HCD_{max} = 600 - 851.2\ln(f)$ ……………………… eqn(1),

where HCD_{max} is the maximum depth for hydrocarbon below the sea surface at a frequency f.

3 Conclusion

The work presented in this paper shows the relationship between target depths of hydrocarbon reservoirs and changes in the antenna frequency. It has been noted that decrease in the antenna frequency will produce a better resolution on the e-field contrast when evaluating models with and models without hydrocarbon. A relationship between the any frequency and the maximum depth of detectable reservoirs has been established and given by the equation

$$HCD_{max} = 600 - 851.2\ln(f)$$

where HCD is the hydrocarbon depth below the sea floor and f if the frequency. The study also shows that lower frequencies allows for exploration of deeper HC reservoirs compared to higher frequencies. For larger fields up to 100 km by 100 km a lower frequency is most suitable to navigate the entire sea bed compared to a higher frequency.

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