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Magnitude Verses Offset Study with EM Transmitter in Different Resistive Medium

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Abstract: Seabed Logging (SBL) is new technique to detect hydrocarbon reservoir under the sea bed. EM transmitter is used to transmit low frequency electromagnetic signals into the subsurface layers of the sea bed to detect different resistive layers. However, detection of resistivity contrast in different resistive layers for a deep target is still a challenge in SBL. Due to economical point of view a scaled tank with a scale factor of 2000 was built to study the resistivity contrast. In the scale tank experiment aluminium rod EM transmitter of length 50 cm is towed at 35 cm height from the bottom of the tank. Three receivers are placed at 25 cm from the bottom of the tank. A series of experiments were conducted with different resistive mediums such as (tap water, salt water and salt water with oil packets). The oil packets were placed at certain positions in the water tank. The electromagnetic field responses from different resistive layers were recorded by the receivers. Different response in the magnitude of magnetic field was observed by different resistive medium. It was also observed that the magnetic field strength had increased 50% for salt water and 150% for oil which clearly shows the resistivity contrast. Our preliminary results have shown that high resistive layers in a conductive medium can be detected by using the experimental set up.

Key words: CSEM, electromagnetic, hydrocarbon, SBL, scale factor, transmitter

INTRODUCTION

Sea bed logging is an application of control source electromagnetic (CSEM) method for the detection of hydrocarbon reservoir in the subsurface of sea bed. In this method a horizontal electric dipole antenna (HED) is used to transmit electromagnetic waves in the sea water and underlying sea bed. Dipole antenna is towed by a surface vessel at a short distance from the sea floor. Low frequency EM waves ranges from 0.25 to 10 Hz is used. This low frequency electromagnetic wave penetrates from sea water into the underlying subsurface of sea bed. Attenuation of this low frequency EM waves is more in a conductive medium and less in resistive medium due to the skin depth. Electromagnetic wave is guided back from the high resistive layer to the sea floor and detected by the detectors which are placed on the sea floor (Cox *et al*., 1986; Ellingsrud *et al*., 2002; Sinha *et al*., 1990). The CSEM method depends on the large resistivity contrast between the hydrocarbon reservoir and the surrounding layers of different resistivity.

Hydrocarbon reservoirs have resistivity of a few tens of Um or higher, where as the resistivity of the over and under-lying layers is less than 2 Um. The hydrocarbon reservoir can be detected due to this resistivity contrast. Sea bed logging is an outstanding technique to detect the hydrocarbon under the sub surface of sea bed. The first scaled experiment was performed to confirm the different resistive layers were reported by Loseth *et al.* (2008), Eidesmo *et al.* (2002) and Young and Cox (1981).

The electromagnetic waves from the EM transmitter diffuse in all directions. The detectors at the sea floor record three kinds of waves. First kind of wave is direct wave transmitted directly from the sea water to the sea floor detectors. Second is air wave which is reflected and refracted through the water air interface. Third is the guided wave which is reflected and refracted from high resistive layers under the sea bed. The electromagnetic waves which are refracted back from the high resistive subsurface layers predict about the hydrocarbon. If the depth of the buried hydrocarbon is less from the sea bed then the refracted signal from the high resistive reservoir can be distinguished from other resistive layers. If the high resistive layer target is deeper at that particular frequency the response from the high resistive layer cannot be predicted (Webb *et al*., 1985; Chave *et al*., 1982; Unsworth , 1994; Webb and Cox, 1982).

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In this study, a scale tank is built with a scale factor of 2000 to study the different resistive layers and to detect the high resistive layer present in a conductive medium.

MATERIALS AND METHODS

Experimental set up: The experimental setup consists of a large water tank as shown in Fig. 1. The tank has a surface area of 1.82 m by 0.91 m and depth of 0.61 m. A conductive environment was created by filling the entire tank with saltwater. A resistive layer was constructed by perspex sheet 4 mm thickness. This construction has a length of 0.5 m, width of 0.25 m and depth of 0.20 m. The perspex was filled with oil packets held in a horizontal position at 0.20 m depth from the salt water surface. The aluminum rod EM transmitter was used as the source. This transmitter was constructed from 50 cm aluminium rod. Three receivers were placed in the water tank at the height of 25 cm from the bottom of the scale tank. The square wave 20 V peak to peak and 1 KHz frequency was applied to the transmitter by a function generator. EM transmitter was towed at the height of 35 cm from the bottom of the scale tank. The resistivity of different medium such as tap water (40 Ωm) salt water (1.38 Ωm) and oil (500 Ωm) were measured by resistivity meter model MC-MR-III. The series of experiments were conducted with EM transmitter in different resistive medium. The transmitter was moved towards and away from the three receivers. The first set of experiment was done with tap water. The second set of experiment was done with salt water. The third set of experiment was done by salt water with oil placed at different positions as shown in Fig. 2. Magnetic field produced by the EM transmitter detected by fluxgate magnetic field sensor Mag-03MSS100. Experimental data were recorded in tap water, salt water and oil at different positions by the decaport data acquisition system Model NI PXI-1042 as a function of source receiver offset as shown in Fig. 3. The values of resistivity of tap water, salt water and oil measured by the resistivity meter is shown in Table 1.

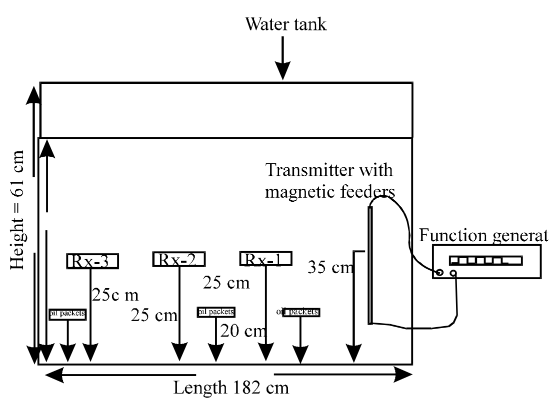

Fig. 1: Schematic diagram of experimental set up of a scale tank

Scale factor calculations: The purpose of this scaled experiment is to detect the different resistive layers. The ratio of the full scale and the laboratory scale dimensions as given by Parasins (1997).

Table 1: Measured value of resistivity of tap water saltwater and oil

	Measured value of resistivity	
Tap water	Salt water	Oil
40 Ωm	1.38 Ωm	500 Ωm

Fig. 2: Experimental set up of EM transmitter with three sensors

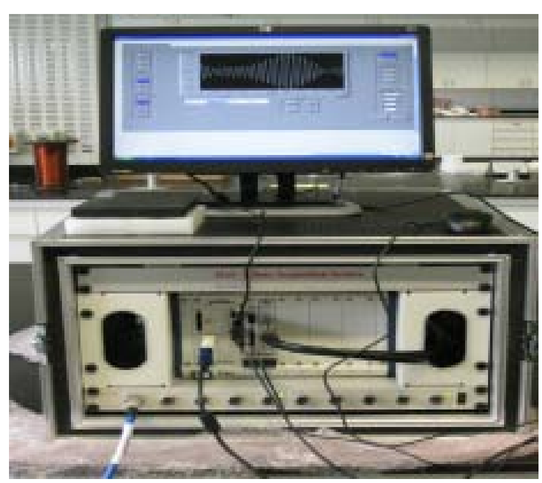

Fig. 3: Data acquisition system for EM data storage

$$\frac{d_{fs}}{d_{1ab}}=n \quad (1)$$

$$\left(\frac{\rho}{\mu f}\right)_{fs}=n^2\left(\frac{\rho}{\mu f}\right)_{1ab} \quad (2)$$

Full scale dimensions are represented by d_{fs} and lab scale dimensions are represented by d_{lab} where P is the conductivity of the medium, μ the permeability of the medium and f is the frequency of the transmitter:

$$\left(\frac{\rho}{f}\right)_{fs}=m^2\left(\frac{\rho}{f}\right)_{1ab} \quad (3)$$

For the frequency:

$$\left(\frac{1}{f}\right)_{fs}=n_2\left(\frac{1}{f}\right)_{1ab} \quad (4)$$

$$n^2 f_{fs}=f_{1ab} \quad (5)$$

The 1 kHz frequency used in the water tank scale down by a factor of 2000 corresponds to 0.5 Hz full scale frequency. The scale tank resistive layers thickness with the scale factor of 2000 relates to the shallow water environment.

Skin depth and wavelength: The attenuation of electromagnetic wave in different resistive mediums can be calculated by the skin depth equation given by:

$$\delta=\sqrt{\frac{2}{\mu_0\rho\omega}} \quad (6)$$

$$\lambda=2\pi\delta \quad (7)$$

where, ω is the angular frequency of the electromagnetic wave signal, P is the conductivity of the medium in which EM wave propagate and μ_0 the permeability of free space. Skin depth shows how far the EM wave penetrates into the medium. The skin depth is large for high resistive medium and has less attenuation than low resistive medium. Similarly if the skin depth is shorter the response of electric or magnetic field is decreased. In sea bed logging the low frequency is used to get less attenuation and more skin depth to get the response of electric or magnetic field from high resistive medium. Low frequency EM signal decrease exponentially with the increase of distance by a factor of $e^{-z/\delta}$.

RESULTS AND DISCUSSION

The CSEM method depends on the large resistivity difference between hydrocarbon reservoir and the surrounding resistive layers. Hydrocarbon reservoir have a resistivity of a few tens of Um or higher, whereas the resistivity of the over and under-lying sediments are in generally less than 2 Um. It will be demonstrated that this resistivity contrast has a visible influence on CSEM data collected at the sea bed above the reservoir, even though the hydrocarbon bearing layers are thin compared to their depth.

Both magnitude and phase of electric or magnetic field provide useful information of different resistive layers. Figure 4 shows the magnetic field response of three receivers as a function of source receiver offset for tap water. The (dash dotted and Solid) line curves show receiver (1-3) magnetic field response as a function of source receiver offset. It was found that three receivers give same response of magnetic field recorded in the tap water with three receivers. This behavior indicates that the medium has the same conductivity and no other conductive medium was present.

Figure 5 shows the magnetic field response for each of three receivers as a function of source receiver offset in salt water. The magnetic field recorded in the salt water had larger amplitude as compared to tap water. There is no sharp increase or decrease of magnetic field of three receivers. This is due to the change of conductivity of the medium from tap water to salt water.

Figure 6 shows the comparison of magnitude verses offset (MVO) in tap water and salt water with three receivers placed in a scale tank at equal distance from each other. It was found that 50% increase in magnetic field strength in case of salt water as compared to tap

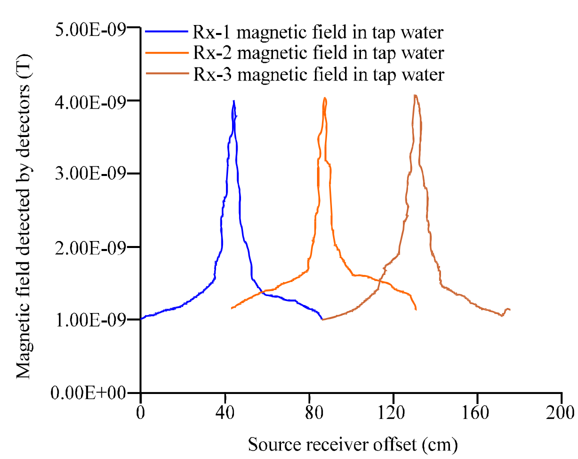

Fig. 4: MVO in tap water with three receivers

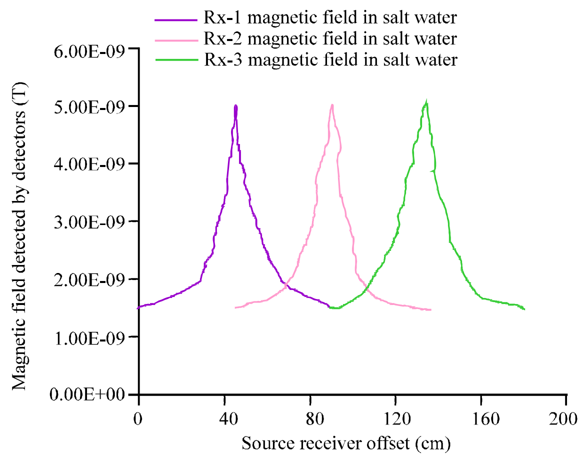

Fig. 5: MVO in salt water with three sensors

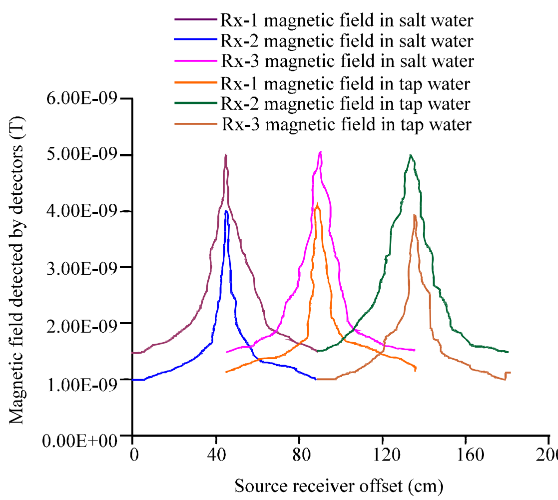

Fig. 6: MVO comparison in tap and salt water with three sensors

water at the tail of the curves of three receivers response due to the change of conductivity of the medium.

The oil packets are placed on the left side of Rx-1 in a perspex sheet at the height of 20 cm from the bottom of a scale tank. The resistivity of the oil is larger than the tap and salt water. The dash line on the left side of the curve shows the magnetic field response of Rx-1. Magnitude of magnetic field on the left side is larger as compared to the right side curve of Rx-1. The other receivers Rx-2 and Rx-3 curves show the same magnitude of magnetic field detected by the receivers. The change of magnetic field magnitude on the left side of Rx-1as shown in Fig. 7 indicates that a high resistive layer is present on the left side of Rx-1.

The oil place was changed from Rx-1 to the left side of Rx-2. It was observed that there is same change of magnetic field response of Rx-1 and Rx-3 as shown in Fig. 8. It was observed that on the left side of Rx-2 there

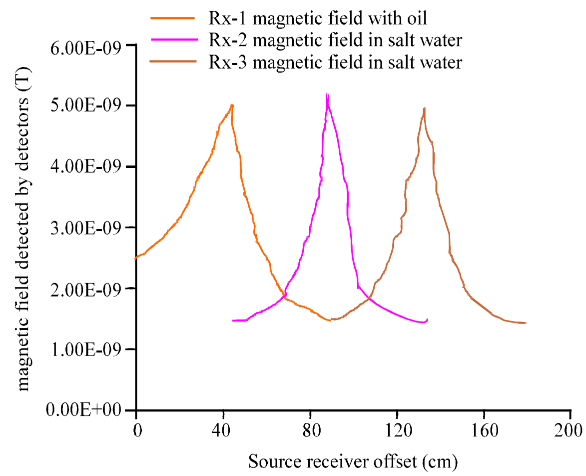

Fig. 7: MVO with oil placed to the left side of Rx-1

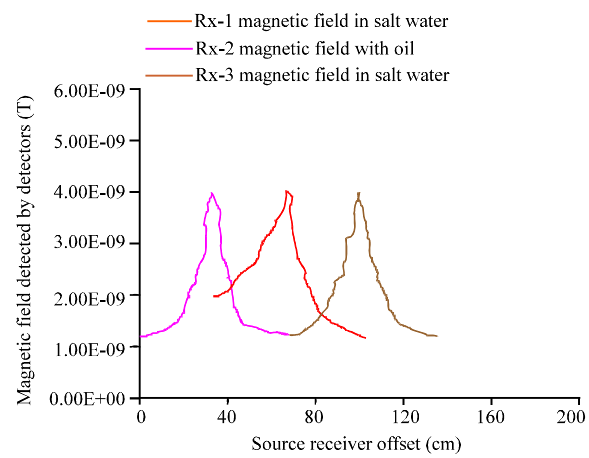

Fig. 8: MVO with oil placed to the left side of Rx-2

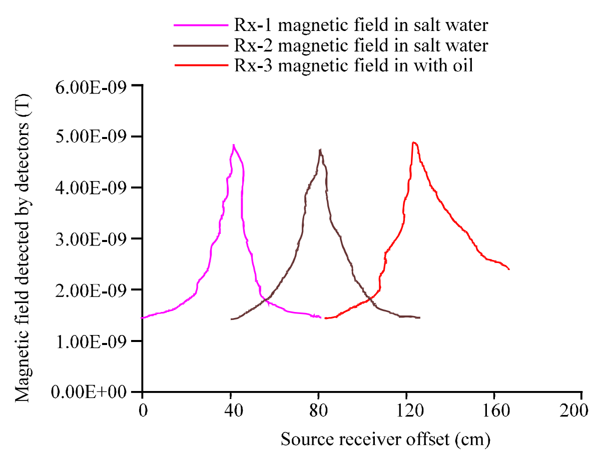

Fig. 9: MVO with oil placed to the right side of Rx-3

was increased in magnetic field magnitude due to the increase of resistivity.

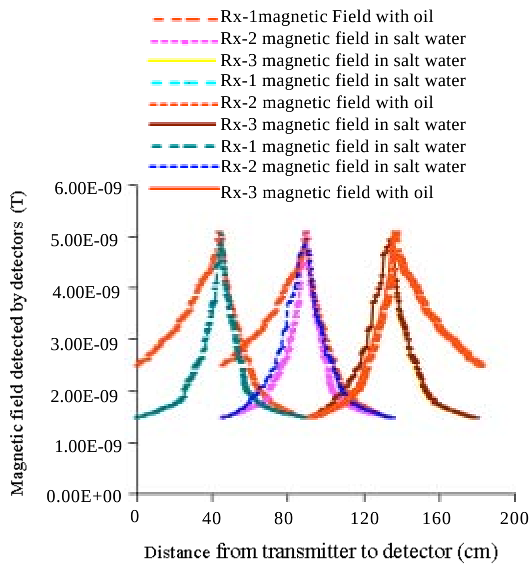

Fig. 10: MVO comparison of three receivers with oil

Table 2: Measured values of magnetic field magnitude with different resistivity at the tail of the curves

Mediums	Magnetic field at the tail of the curve	% increment of magnetic field magnitude at the tail of the curve
Tap water	1 nT	-
Salt water	1.5 nT	50
Salt water with oil at different locations	2.5 nT	150%

The magnetic field produced by EM transmitter is not confined to the horizontal plane and pass through the different resistive layers. Sea floor measurements of the electric or magnetic field are sensitive to the presence of resistive layers. The oil position was changed from Rx-2 to the right side of Rx-3. Same change of magnetic field magnitude of Rx-1, Rx-2 and the left side of Rx-3 was observed as shown in Fig. 9. When the high resistive layer is present more EM waves guided back therefore more EM waves are detected. That's why increase in magnetic field magnitude on the right side of Rx-3 was observed.

Comparison of magnetic field response with three receivers as a function of source receiver offset with salt water and with change of position of oil as shown in Fig. 10. The increase in magnitude of magnetic field on the left side of Rx-1, Rx-2 and on the right side of Rx-3 indicates that high resistive layer is present at these locations. It was concluded that the magnetic field magnitude detected by the receivers increased by 150% for oil and 50% for salt water.

The magnitude of magnetic field response by the receivers in a scale tank with different resistive medium at the tail of the curves is shown in Table 2.

CONCLUSION

The tail of MVO is very important because it gives the information about different resistive layers present in a conductive medium. This experiment confirms that we are able to detect a high resistive layer in a conductive medium by using electromagnetic waves in a designed scale tank. It was observed that 50 and 150% increase the magnitude of magnetic field response with salt water and oil which clearly shows the resistivity contrast.

ACKNOWLEDGMENTS

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