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Tracing buried pipelines using multi frequency electromagnetic

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Abstract In this paper the application of multi frequency electromagnetic techniques to locate buried pipelines is described. The survey site has two pipelines of SUMED, one of the world chokepoints. At desert or arid areas, regular geophysical surveys usually are difficult to carry out. EM techniques could be the best among geophysical techniques to be used for this target at these conditions. The EM survey was performed using a GEM-300 multi-frequency electromagnetic profiler. It is of handheld electromagnetic induction-type that measures in-phase and quadrature terrain conductivity without electrodes or direct soil contact. An area of 60×15 m was surveyed, that supposed SUMED pipeline existed. Six different frequencies, typically 2025, 2875, 4125, 5875, 8425, 12,025 Hz, have been used simultaneously. The slice maps for in-phase and conductivity distribution at each frequency could help to trace the extension of the pipeline. Two pipelines were traced successfully with 20 m spacing of each others.

1. Introduction

Oil is and will continue to be, for decades to come, the main source of energy for both the developed and developing countries all over the world. In 2011, total world oil production amounted to approximately 87.5 million barrels per day (bbl/d), moved by tankers on fixed maritime routes or via pipeline routes such as these chokepoints (Fig. 1) (IMO, 1982; Rodrigue, 2004;Swift, 2005; ITOPF, 2008).

Sea transport will continue to be the main transportation means to move oil and oil products from producing countries to consumers all over the world. Pipelines, on the other hand, are the mode of choice for transcontinental oil movements. Pipelines are critical for landlocked crudes and also complement tankers at certain key locations by relieving bottlenecks or providing shortcuts. Pipelines come into their own in intra-regional trade. They are the primary option for transcontinental transportation, because they are at least an order of magnitude cheaper than any alternative such as rail, barge, or road, and because political vulnerability is a small or

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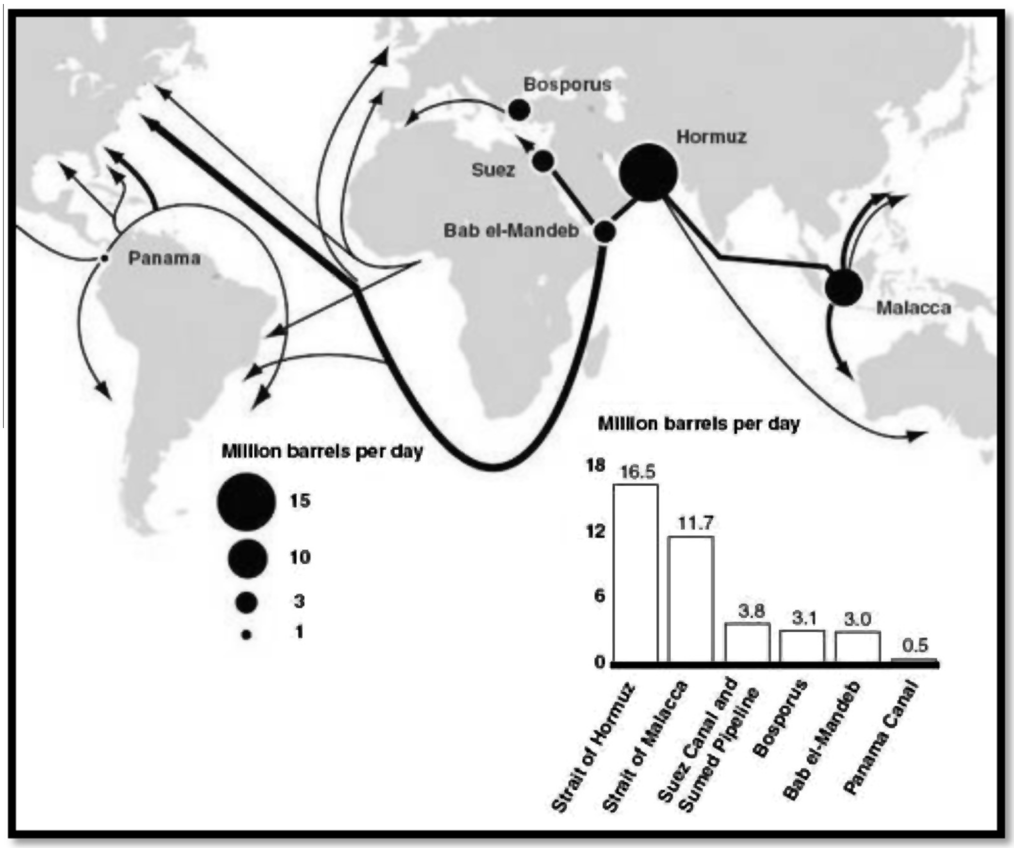

Figure 1 Oil flow and chokepoints, 2003.

non-existent issue within a nation's border or between neighbouring countries (Greene et al., 2003; TRB, 2004; Rodrigue et al., 2009).

One of the world chokepoints is the Suez-Mediterranean (SUMED) pipeline. The Arab Petroleum Pipelines Co., commonly known as SUMED, operates a 2.4-million barrel per day (bpd) crude oil pipeline in Egypt. The 200-mile long SUMED Pipeline provides a route between the Red and Mediterranean Seas by crossing the northern region of Egypt from the Ain Sukhna to the Sidi Kerir Terminal (Fig. 2). This provides a short-cut to the Mediterranean and northern European ports for cargoes that would otherwise have to circumnavigate Africa (Rodrigue, 2004).

Oil pipelines are made from steel or plastic tubes with inner diameter typically from 4 to 48 in. (100 to 1200 mm). Most pipelines are buried at a typical depth of about 3 to 6 feet (0.91 to 1.8 m). The oil is kept in motion by pump stations along the pipeline, and usually flows at a speed of about 1 to 6 m/(TRB, 2004). Considering these parameters, geophysics can play an important role in tracing and regular checking of such kinds of pipelines.

Several geophysical techniques had been used for a long time in mapping and locating superficial objects including pipelines but not limited to magnetics, VLF-EM, Very Low Frequency (VLF) electromagnetic, Time domain electromagnetic; electrical resistivity; Ground Penetrating Radar (GPR) and limited trials of using Frequency Domain electromagnetic (FDEM) (Gay, 1986; Won and Huang 2004; Bosch and Muller, 2005; Babu et al., 2007; Auken et al., 2006; Panissod

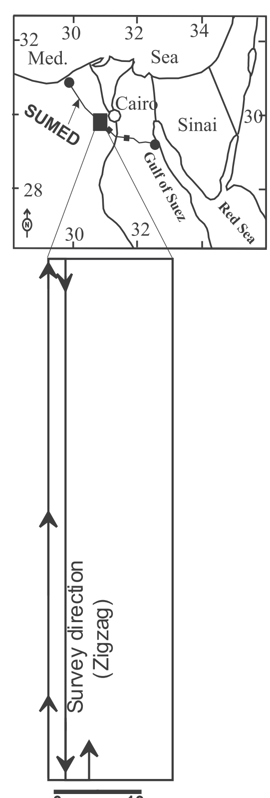

Figure 2 Sketch for SUMED pipeline and location of study area.

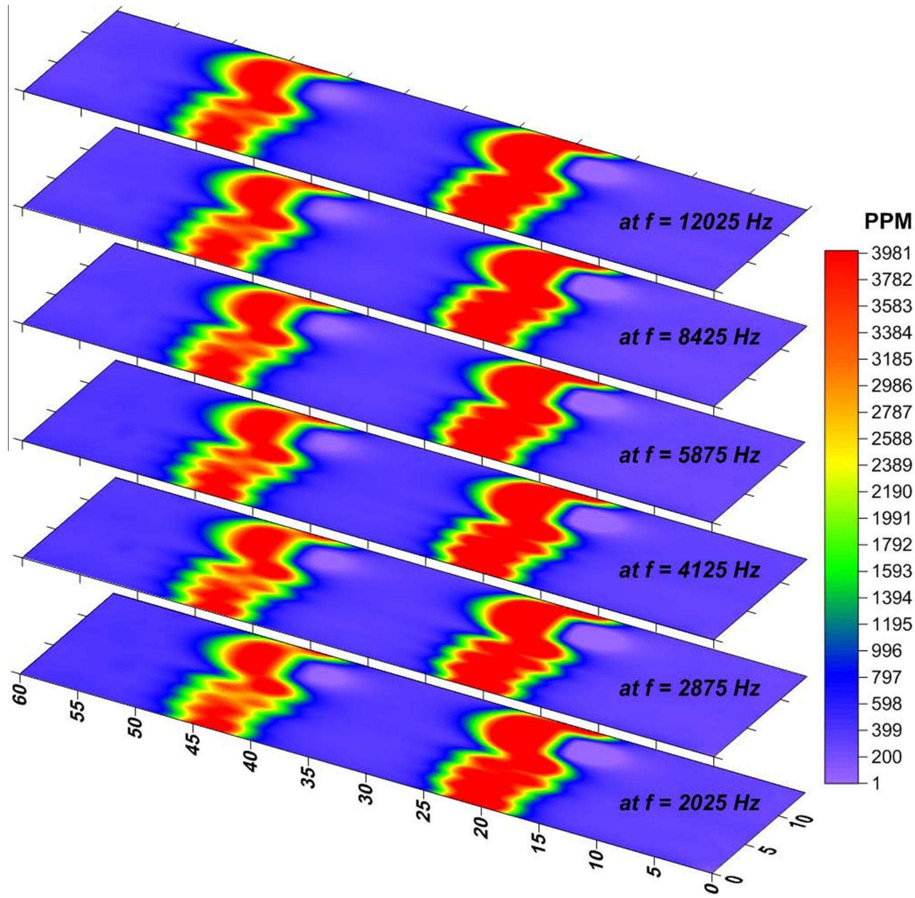

Figure 3 In-phase response at all frequencies measured in the study area.

et al., 1998; Birken et al., 2002; Borgioli et al., 2008; Soliman and Wu, 2008; Huang and Won 2000). However the local site conditions, the depth of the buried target and the primary requirements of the survey limited the valid exploration technique to provide; non-destructive technique, low cost survey, speed of data acquisition, rapid data processing steps, sensitive to small background contrast and less affected with the closely background noise sources.

One of the most frequently applied techniques in the field of pipeline detection is the GPR. It has been applied for detecting different varieties of underground pipelines and also at different depths (Kovas, 1991; Tong 1993; Zeng and Mcmechan 1997; Wang 2006 and others). However the deep pipelines (> 4 m depth) and those buried in conductive subsurface medium make a severe attenuation for the GPR wave and hence cannot detect the pipelines effectively (Porsani et al., 2012).

In this work, a case study to imagine the SUMED pipelines at the south western side of greater Cairo is presented in a trial to highlight the efficiency of the frequency domain electromagnetic geophysical survey to help tracing such pipelines.

2. Multifrequency electromagnetic method

The EM is a non-invasive technique that can cover a large area quickly thereby reducing costs and logistical effort because a single person can do a survey in a relatively short time (Won, 1980; Mares, 1984).

EM instruments were developed originally to search for conductivity anomalies due to highly conductive object in the ground such as ore bodies or buried tanks (Won et al., 1998). Other common fields of application are the mapping of basic soil layers or the determination and monitoring of soil salinity (Lesch et al., 1995; Huth and Poulton, 2007).

The Frequency-domain EM method creates a primary electromagnetic field which induces eddy currents in the subsurface material. These in turn induce a secondary electromagnetic field, which modifies the total field. The difference between these two fields is a function of the subsurface conductivity (McNeill, 1990, Nabighian, 1991). The EM records the magnetic intensity of the secondary field that is given by the equation (Mares, 1984):

$$H(t) = H_0 \cos(\omega t - \varphi) \quad (1)$$

where H_0 is the primary magnetic field, ω is the angular frequency and the angle ϕ determines the phase delay. The phase delay is caused by the short amount of time the particles in the ground need to adjust to the imposed field. The quantities which display a zero phase delay are referred to as in-phase quantities and the quantities which are displaced in phase with respect to the source current by 90° are referred to as in quadrature. The apparent conductivity is therefore related to the measured quadrature phase values (Won, 1980 and Won et al., 1997):

$$\text{Cond} = 360 * \text{PPM(Q)}/\text{Freq} \quad (2)$$

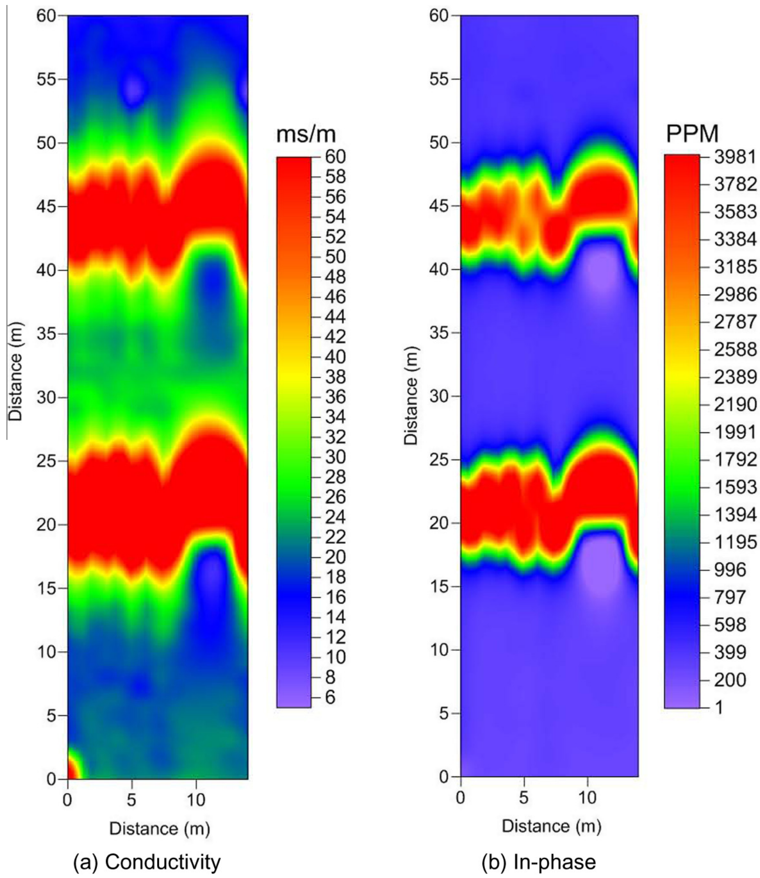

Figure 4 In-phase and conductivity results at frequency 2025 Hz.

Cond is the conductivity in units of mS/m
PPM(Q) is the quadrature phase reading
Freq is the frequency in Hz

This relationship in Eq. (2) is valid only for surveys over poorly conductive ground such as the case in this study with an induction number smaller than one. The induction number is defined as intercoil spacing (1.67 m for the GEM-300) divided by the skin depth. The skin depth can be derived from a special nomogram (Won et al., 1998).

3. Description of the survey site

A 60 m by 15 m grid was surveyed on one area supposed to include the two SUMED pipelines south west of Cairo, Egypt. The EM survey was performed using a GSSI, GEM-300 system (GSSI, 1998), by walking along lines with 0.5 m between lines (Fig. 2). A GEM-300 system consists of a transmitter coil with an alternating current running through it, inducing an electromagnetic field at different frequencies. Six different frequencies were registered within the same measuring cycle. The GEM transmits frequencies within the range from 325 to 19,975 Hz. In this survey the frequencies 2025, 2875, 4125, 5875, 8425, 12,025 Hz are used. Then the receiver unit records the in-phase and quadrature components of the returning signal. The data for both phases are converted into a PPM unit as follows: (Won et al., 1998).

$$PPM = 10^6 * \frac{H_s}{H_p} \quad (3)$$

where H_s is the secondary magnetic field at the receiver coil and H_p is the primary field at the receiver coil.

The GEM-300 offers different survey modes. One can either perform a continuous survey or station wise measurements. Both modes are applicable to all user-defined grids. The continuous mode is a very fast way to do a survey with a flexible grid that needs only the grid end points to be laid out. The 'station wise' survey offers the option of very accurate positioning of the measurement points within a user-defined grid. In this work, a station wise mode was selected with 0.5 m station distance along the line (Fig. 2).

A control processor unit runs the system software, manages the power and stores temporarily the measured data. The measured values can easily be transferred into a computer and then into a plotting programme to display the data as 2D contour maps such as shown in Figs. 3–6.

4. Result

Based on the acquired data sets along the proposed pipelines, Fig. 3 presents the in-phase results as filled colour slice contour plots showing relative EM values in parts per million (ppm) across the surveyed area at those six different frequencies. It is clearly noticed, at all frequencies a linear anomaly existed around 20 m distance from the zero point of the surveyed area,

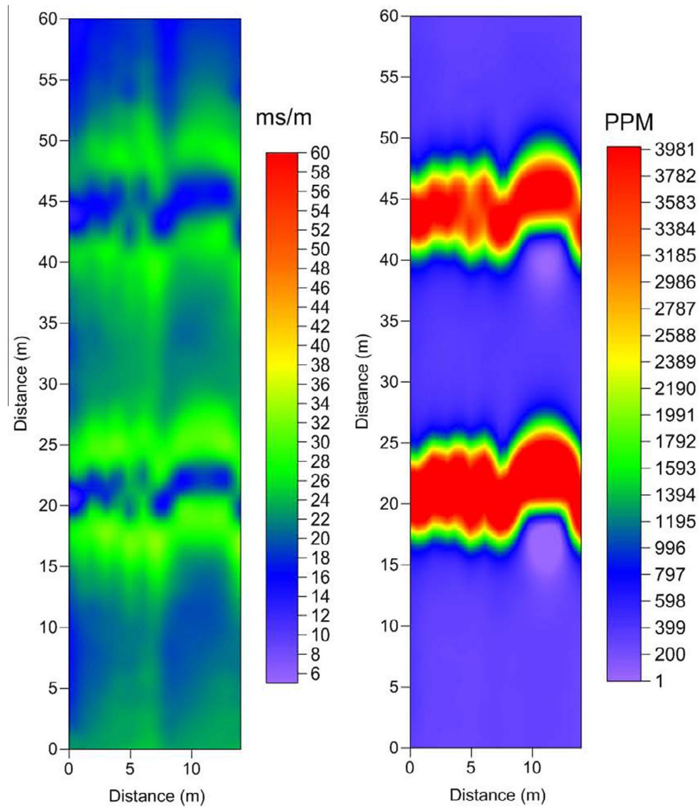

Figure 5 In-phase and conductivity results at frequency 12,025 Hz.

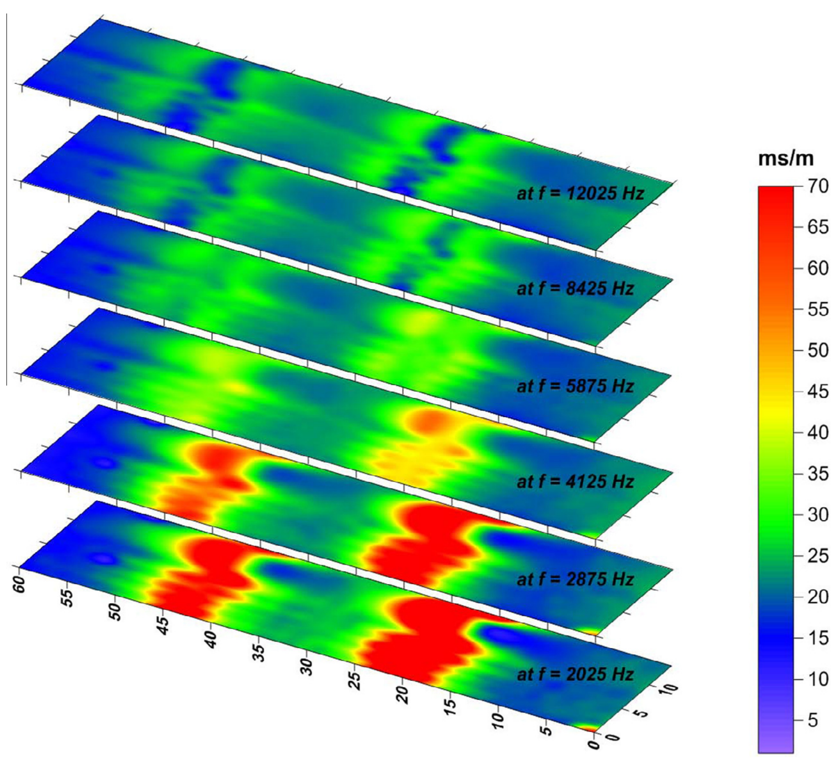

Figure 6 Image of conductivity distribution at different frequencies (ms/m).

while another anomaly existed around 45 m. Those two linear anomalies correspond to the two SUMED pipelines.

More representation for the detected pipeline can be shown in Fig. 4, where the contour plot of conductivity and in-phase components of the measured data using a frequency of 2025 Hz are displayed in Fig. 4(a) and (b) respectively. Going up to display the shallow features by increasing the frequency to 12,025 Hz, the conductivity and in-phase components of the measured data have been displayed in Fig. 5. It is noticeable in the conductivity maps at both Figs. 4 and 5 that the sizes of the two anomalies that represent the relative high conductivity features for the two pipes are getting slightly wider at higher frequencies, in other words, at shallow depth. This probably can be interpreted in two possible ways. The first is that as we are getting shallower, the size of the object, pipeline, is getting exaggerated, hence appears wider in size, considering that the effective anomaly size (conductivity features) of the interpreted pipe is affected by the type of the host sediments and almost its dimensions are larger than the real. The other possible interpretation is that the contents of the pipeline, which is the crude oil has relatively lower conductivity than the pipeline itself, hence make distortion to the anomaly and cause another local relatively, low conductivity at the centre of the object itself. Fig. 6 illustrates slice conductivity contour maps at all measured frequencies. For either interpretation, the induction EM technique shows a high efficiency in locating the SUMED pipelines at the arid desert area.

5. Conclusion

The Frequency domain EM induction technique has been applied for locating subsurface pipelines at arid areas such as the dry desert of Egypt. The multi frequency induction GEM-300 system was used. In-phase and quadrature phases had been measured at six different frequencies simultaneously. Both FDEM components reflect clearly in a fast and reliable way the location of the two pipelines along the surveyed area. As long as the frequency increases the depth of investigation getting to be shallower and the detectable pipelines anomalies became slightly smearing and wider.

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