Delineating fresh groundwater aquifer within sub-seafloor sediments offshore Israel using a short offset marine TDEM system

Mark Goldman[1,2], E. Levi[1,2], U. Kafri[3], B. Tezkan[4], P. Yogeshwar[4], B. Herut[2,5] and G. Tibor[2,5]

[1] Geoelectric Department, Geophysical Institute of Israel, Lod, Israel
[2] Department of Marine Geosciences, University of Haifa, Haifa, Israel
[3] Geological Institute of Israel, Jerusalem, Israel
[4] Institute of Geophysics & Meteorology, University of Cologne, Cologne, Germany
[5] Israel Oceanographic and Limnological Research, Haifa, Israel

ABSTRACT

A novel marine time domain electromagnetic (TDEM) geophysical technique has been developed to delineate the offshore extension of a deep fresh groundwater body previously detected within deep confined sub-aquifers of the Mediterranean coastal aquifer of Israel.

The method employs a floating grounded line (horizontal electric dipole) transmitter and a short offset broadside horizontal coil (vertical magnetic dipole) receiver located at the sea floor. Traditionally, such an array was considered as an outsider for exploring electrically resistive targets (e.g. fresh groundwater, gas hydrates, hydrocarbons, etc.) particularly in highly conductive environments such as sub-seafloor sediments. Unexpectedly, it was found that, if the receiver is placed between the transmitter and the coastal line, the sharp sea-land resistivity contrast significantly enhances the resolving capability of the measurements thus making such system the leading one for near-shore measurements.

Several offshore TDEM traverses using the above system were run both in parallel (south-north) and perpendicular (east-west) directions to the coastal line. All the results clearly exhibited the existence of a relatively resistive structure in the lower portion of the sub-seafloor aquifer within approximately the same depth range as it was detected onshore underneath the seawater intrusion into the coastal aquifer.

INTRODUCTION

The existence of submarine fresh groundwater bodies extending offshore to distances between a few meters to several tens of kilometers was reported from all over the world. The most prominent examples are offshore Guyana, Suriname, New Jersey, New England continental shelf and the Netherlands (e.g. Kooi and Groen, 2001).

This phenomenon is commonly known under the name “submarine groundwater discharge (SGD)”. The general conceptual model of SGD shown in Figure 1, suggests two different pathways of the discharge: the shallow one through the upper phreatic sub-aquifer(s) and the deeper one through the lower confined sub-aquifer(s).

For a long time, the shallow SGD has been studied by both manual and automatic direct measurements, such as seepage meter measurements, heat-pulse measurements and by using various (mainly geochemical) tracers. During the last years, geophysical, mainly resistivity measurements began to be widely applied in shallow SGD studies.

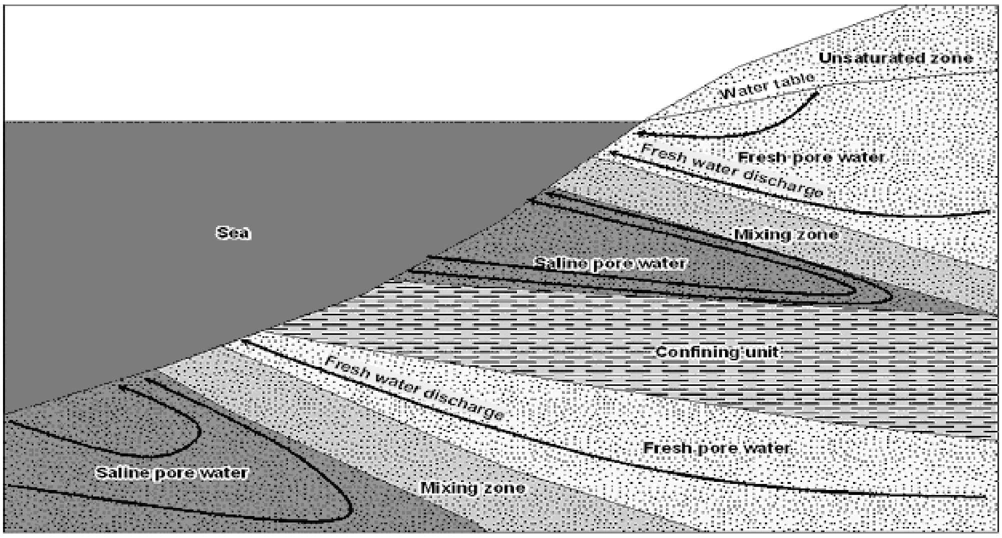

Figure 1. General conceptual model of SGD (after Swarzenski *et al.*, 2004).

Unfortunately, most of the above mentioned techniques are hardly applicable for studying deep SGD. Moreover, in some cases, the confining unit can block the lower sub-aquifers from the sea bottom, so that no discharge takes place and, strictly speaking, there is no SGD at all. In this case, the only way to detect the existence of a freshwater body below the sea bottom (except for expensive drilling) is by conducting off-shore geophysical surveys.

Such conditions presumably exist offshore the Mediterranean coast of Israel, where recent onshore TDEM measurements close to the shoreline proved the existence of fresh water bodies within lower (confined) sub-aquifers of the coastal aquifer underneath the seawater intruded upper sub-aquifers (Kafri and Goldman, 2006). It is reasonable to assume that these bodies extend offshore beneath the sea bottom and the detected low salinity of these bodies could be caused (among others) by the blockage of the lower sub-aquifers to the sea that prevents seawater encroachment into them.

Although marine geoelectromagnetic investigations became very popular for deep offshore hydrocarbon exploration (Constable, 2006), almost no similar surveys have been carried out for the exploration of deep SGD and/or confined submarine freshwater bodies. One of the very few (if not the only one) of such surveys has been conducted in the Netherlands, where the extension of a freshwater body beneath the seafloor was detected to approximately 1.5 km off the coast by using a surface floating offshore time domain electromagnetic (TDEM) system (Groen *et al.*, 2005). It is clear, however, that such system is not efficient both technically/logistically (floating large loops) and geophysically due to a low sensitivity to highly resistive sub-seafloor targets. Such targets (mainly deep hydrocarbon deposits) are presently explored by using electrical transmitter and receiver dipoles mainly in frequency domain, but these methods are not applicable in shallow waters due to the so called air-wave effect.

METHOD

The method developed in the present study is in a sense a compromise between the above mentioned systems. It comprises a floating electrical transmitter dipole AB and a bottom located vertical magnetic dipole (horizontal coil) Bz (Fig. 2). In 1D earth, such system (termed AB-Bz) is identical to the well known in-loop (or central loop) configuration and as such is expected to exhibit a low sensitivity to highly resistive (particularly thin) structures. The AB-Bz array was selected among other arrays mainly for comparison purposes, but turned out to be most suitable for detecting high resistivity sub-seafloor targets, if the offshore measurements are carried out relatively close to the shoreline.

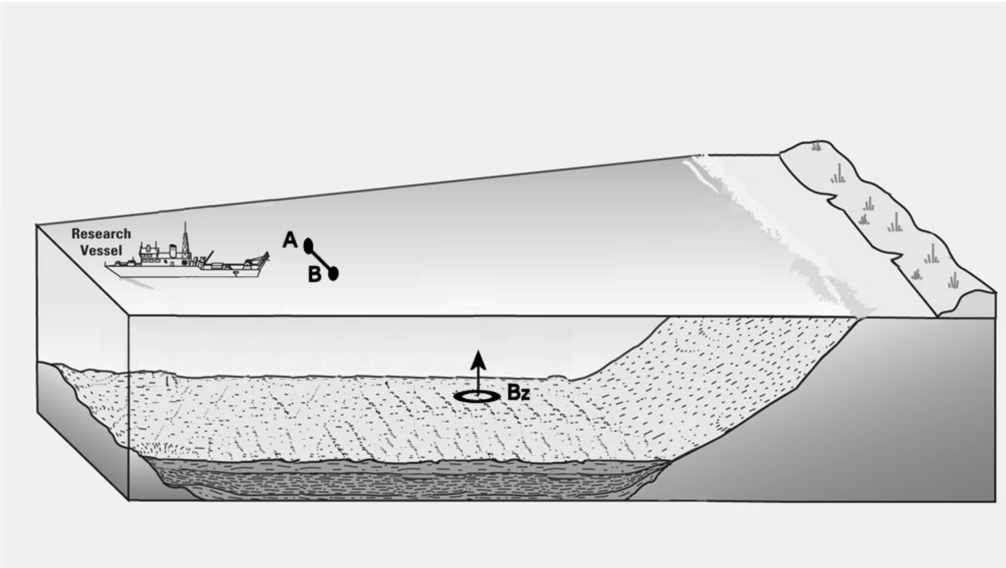

Figure 2. The schematic array used in the offshore survey.

The AB-Bz array used in the present survey included floating 100 m long electric dipole and the standard 100 m^2 Geonics coil (water proofed with a few cm thick polyurethane cover) placed at the sea floor. Most of the measurements were carried out using standard Geonics EM67 instrument providing approximately 20 A current into the transmitter dipole.

RESULTS

A total of 25 offshore TDEM measurements using the above described system was carried out within a maximum of approximately 1 km distance from the shoreline. All the collected data were of a good quality. Most of the measurements showed the existence of a highly resistive body within the sub-seafloor aquifer. Analysis of the results indicated that this body represents the offshore extension of previously detected fresh groundwater within lower sub-aquifers of the coastal aquifer.

Since the developed marine TDEM system is mostly efficient relatively close to the shoreline, only longitudinal dimensions of the target (parallel to the coast) have been accurately estimated in the present survey. This is particularly important due to the limitations of the on-land TDEM measurements, which could not be carried out within the metropolitan Tel Aviv area. These

limitations were overcome in the present survey. As a result, the previously estimated longitudinal dimensions of the freshwater body have been defined significantly more accurate.
As far as the transversal dimensions of the target (perpendicular to the coast) are concerned, they are reliably estimated at present to a distance of approximately 1 km from the shoreline. The perpendicular traverse is planned to be continued during 2010 using alternative geoelectric methods.

CONCLUSIONS

The developed marine TDEM system allows accurate detection of sub-seafloor freshwater bodies within a few km distances from the shoreline. The conducted offshore measurements enable to extend the longitudinal dimensions of the continuous freshwater body for at least another 10 km as compared to the previous estimation based on the on-land TDEM measurements.

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Contact information: Mark Goldman, Geophysical Institute of Israel (GII), Geoelectric Department, 6, Habaal Shem Tov str., Lod 71100, Israel, Phone: 972-89785877, Fax: 972-8920881, Email: mark@gii.co.il