A PROPOSAL FOR

DEEP AQUIFERS INVESTIGATION IN RUB Al KHALI USING MAGNETOTELLURICS

Introduction

The magnetotelluric technique is a passive surface measurement of the Earth's electric and magnetic fields, in the time domain, used to infer the electrical resistivity structure of the subsurface. Regional reconnaissance can be subdivided into (a) detection of sedimentary basins beneath cover and (b) general regional structural interpretation for sitting detailed surveys. These surveys are typically done on a grid with 6 – 10 kilometer station spacing.

The main goal of this study is the assessment and evaluation of the groundwater potential of the Rub' Al Khali deep aquifers by applying the latest geophysical techniques to a better understanding of the hydrogeological systems and their functioning.

Over the past decade or so, we developed expertises in a number of areas that are relevant to integrated geophysical and hydrogeological studies/activities in different regions, where the geophysical methods are the key point that helped to determine the groundwater resources potential, especially for future planning and sustainable development management purposes.

In this proposal, we will adopt Magnetotellurics technique to delineate deep aquifers of RAK in the assigned areas by the prime contractor. This proposal addresses the issue of monitoring and controlling deep-looking EM (Electro Magnetic) geophysical work for the purpose of mapping deep aquifers in the Rub al Khali (RAK). These deep aquifers in the RAK will be referred to hereafter as the RAKAS (RAK aquifer system).

Geologic Setting of the RAK

Precambrian crystalline basement of the Arabian Shield crops out along the eastern margins of the Red Sea coastline forming the westernmost margin of the RAK terrain. The basement complex rocks are impermeable and groundwater in basement areas is found in fractures or in the alluvial aquifers within the wadi network dissecting these domains. Unconformably overlying the crystalline basement are thick sequences of sedimentary formations ranging in age from Cambrian to recent; they dip gently to the east and thicken in the same direction reaching thicknesses of up to 5 km in the vicinity of the Persian Gulf. These stratigraphic relationships are demonstrated in Fig. 1, a generalized schematic cross section along a SW to NE trending transect.

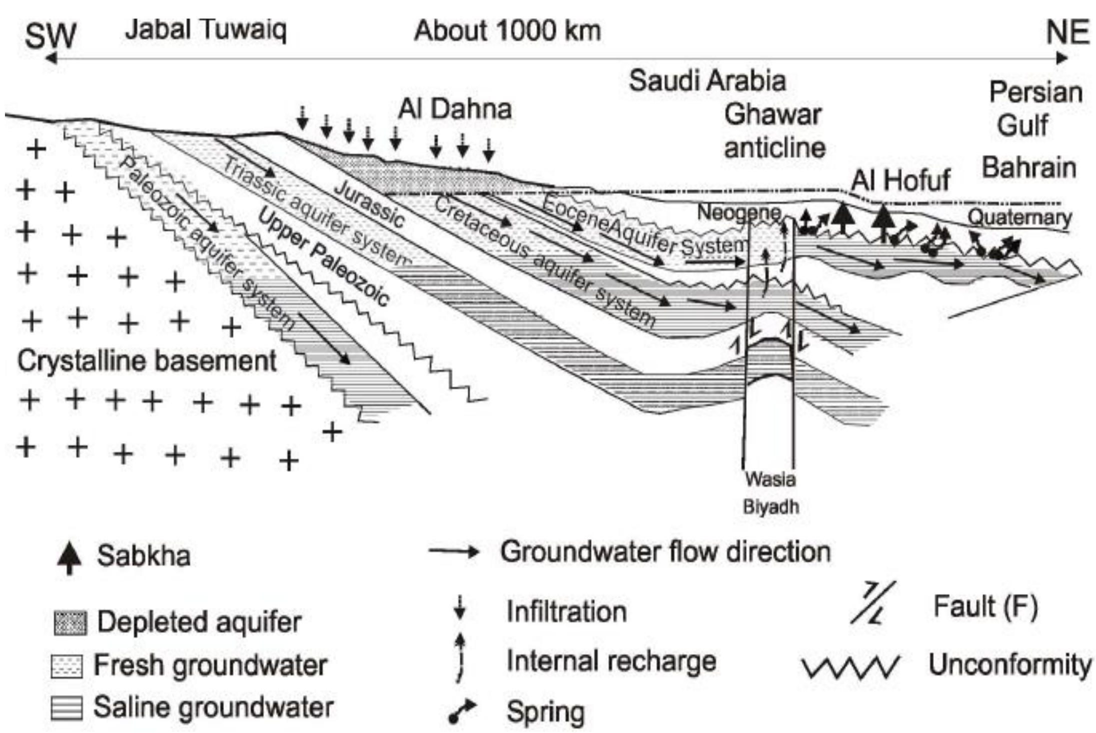


Figure 1. A SW to NE schematic cross section through the RAK modified from Beaumont (1977) and AlSharhan et al. (2001).

Groundwater in the RAK is hosted primarily in sandstone, limestone, and dolomite formations separated by interleaving confining shale units. These aquifers are here grouped in: (1) Paleozoic sandstone aquifers (e.g., Wajid aquifer: 200-900m thick) and limestone and dolomite aquifers of the Kuff formation (250-600m), (2) Mesozoic sandstone aquifer (e.g., Minjur: 400m thick; Biyadh-Wasia: 425m), and (3) Cenozoic (Eocene and Neogene) limestone and dolomite (e.g., Umm er Radhuma: 250-700m; Dammam: 250m) (Al Alawi and Abdulrazzak, 1994; 2001; Ministry for Higher Education, 2000).

These sedimentary formations are exposed in the foothills of the Red Sea Hills providing ample opportunities for groundwater recharge for all aquifers (Cambrian to Quaternary) from rain precipitating over the Red Sea Hills and surroundings. Precipitation is concentrated over the mountain ranges and/or highlands surrounding the area from the east (Red Sea Hills), west (Oman mountains), south (e.g., Hadramount and Dhofar mountains), and north (Yabrin mountains) and is channeled by extensive E-W trending watersheds intercepting the recharge areas. These relationships are demonstrated in Figure 2a, which shows a mosaic of Landsat Thematic Mapper scenes draped over digital elevation data for the RAK and surrounding mountains and a similar drape for the major watersheds and drainage networks in the area (Fig. 2b). The precipitation over the southern and eastern highlands is less likely to recharge the aquifer sequence in its entirety since only the more recent aquifers (Cenozoic) crop out at the foothills of these mountain ranges.

Radiocarbon dating of groundwater samples from a number of these reservoirs (Saq: 22,000-28,000 ka; Biyadh-Wasia: 8,000-16,000 ka; Umm er Radhuma: 10,000-28,000 ka) have lead to interpretations suggesting that these reservoirs were recharged during previous wet climatic periods in the Quaternary (AlSharhan, 2003; Beaumont, 1977; Otkun, 1971). Although we believe that the aquifers are largely formed of fossil water, we suggest that during the intervening dry periods, as is the case now, these aquifers must receive additional recharge given the relatively high precipitation over the Red Sea Hills and the presence of a network of ephemeral streams that can channel these waters to the recharge areas at the foothills of these mountains. This has been demonstrated to be the case in similar settings in the Eastern Desert of Egypt and the Sinai Peninsula (Sultan et al., 2007; 2000).

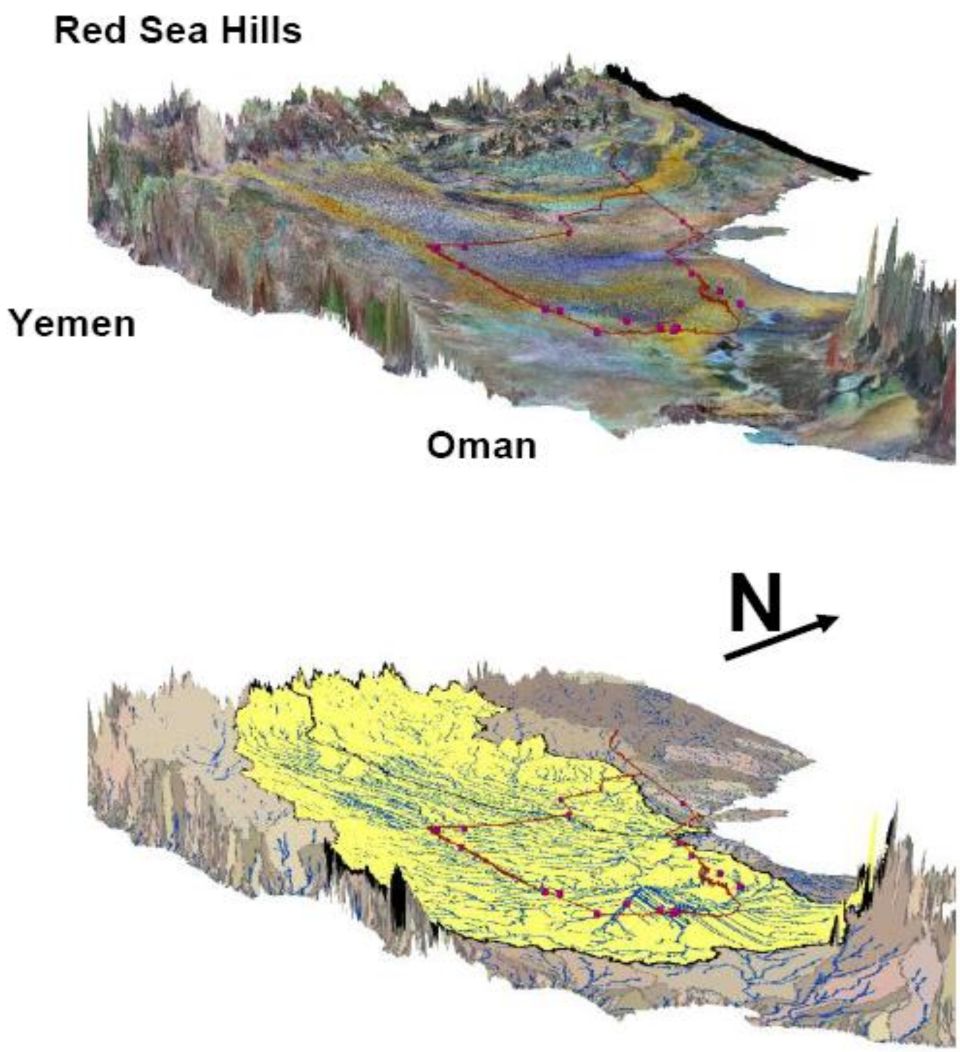


Figure 2 - representations. (a) Landsat TM false color images draped over vertically exaggerated digital elevation data (1 km SRTM). (b) Watersheds and drainage networks extracted from SRTM data draped over 1 km SRTM data. Also shown on Figs. 2a and 2b are our sample locations (red lines).

Methods of Analysis

The magnetotelluric (MT) method uses the time-varying Earth's electromagnetic (EM) field as its source, and depth penetration from a few hundred metres to about 200 km is generally assured. At high frequencies (about 8 Hz and higher), the EM fields penetrate typically to about mid-crustal depths. These variations are caused by distant lightning storms, perhaps half the globe away. The time variations at deep-crustal and mantle-probing depths are caused by the interaction of the solar plasma with the Earth's magnetosphere - the most visible form of this interaction is the *northern lights*. The EM energy from both of these sources is trapped within the Earth-ionosphere waveguide.

EM techniques are sensitive to electrical conductivity. Most aquifers are more electrically conductive than the formations above and below the aquifers. EM techniques are characterized as either "natural source" (no man-made energy source required) or "Controlled Source" (CSEM) which require a man-made power source. The usual EM techniques applied to groundwater exploration and characterization include the controlled-source techniques VES (Vertical Electric Sounding"), dipole-dipole resistivity, TDEM (Time Domain EM), and Frequency Domain EM.

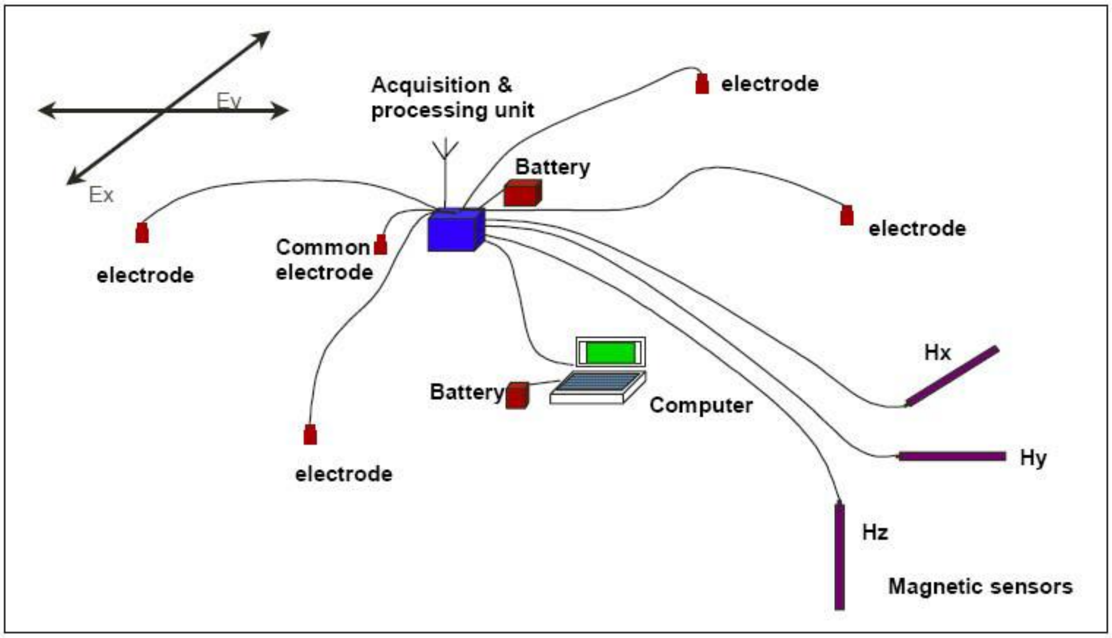
However, all of these are shallow-penetrating techniques. VES and resistivity require the use of a transmitter/motor generator and fuel supply, and also, well-grounded current electrodes (which may be difficult to achieve in the extremely dry surface sands). VES and dipole-dipole resistivity (with typical multi-channel systems) have considerable difficulty seeing below the first conductive layer. VES requires very large current dipoles (expanding up to several km in length) to achieve significant depth of exploration.

TDEM and **FDEM** do not require grounded electrodes, but typical groundwater-oriented FDEM has depth of investigation of usually < 100m, and TDEM, < 300m. As well, TDEM has difficulty seeing through the first conductive layer. The depths in the RAK aquifer systems exceed the capabilities of the usual techniques described above, so to investigate the aquifer formations below the shallowest one, deep-penetrating EM technique(s) are required. The only two CSEM options are CSAMT and LoTEM. Any deep-penetrating CSEM technique requires a powerful motor generator, with ample fuel supply, and a large transmitting antenna. The logistic handicap of CSEM for RAK operations is obvious.

Therefore, the most feasible EM technique to use in this project appears to be MT (Magneto-tellurics), a well-known natural-source geophysical technique (invented in the 1950s) used in exploration for hydrocarbons, geothermal systems, metallic minerals, and groundwater.

The MT signal source is natural fluctuations of Earth's magnetic field. Since no heavy motor generator / fuel supply /large antenna is needed, this greatly simplifies operations in the RAK. MT depth of investigation is >tens of km, which is more than sufficient for this project. MT equipment is relatively compact and light in weight, battery powered, with small footprint and minimal environmental disturbance; and MT provides a rich information set, with dimensionality indicators, etc.

There are five channels of data input at each MT station. These are two components of electric field (Ex and Ey time series) and three components of the magnetic field (Hx, Hy, and Hz time series). Note that boundary conditions require that Ez = 0, so a full three dimensional vector measurement is being made. The electric field components (Ex and Ey) are measured by orthogonal pairs of non-polarizable porous pot electrodes connected by cables. The magnetic field components (Hx, Hy and Hz) are normally measured with ferrous-cored coils.



Typical MT station layout

Note that MT fieldwork has already been carried out in Saudi Arabia for hydrocarbon exploration (Stewart et al, 1996; Al-Dulaijan et al 2008) so there is no doubt that the technique can be applied in the RAK environment. Special equipment (electric field preamplifiers) may be used as required to mitigate the problem of highly resistive surface (dry sand).

Study Area:

The study area as determined by the prime contractor represents a triangle of three wells (RAK 03, RAK 04 and WBA 06). The distances among the wells as follows : WBA 06 – RAK 03 = 167 km ; WBA 06 –RAK 04 = 224 km; RAK 03 – RAK 04 = 174 km. A complete lithological and geophysical log of WBA 06 is available at the prime contractor which will be used as a calibration well (Figure 3). Geographic coordinates of these wells are listed below :

RAK 3 : Lat : N 21° 03 \
Long : E 49 ° 41 \

RAK 4 : Lat : N 20° 06 \
Long : E 48 ° 21 \

RAK6 : Lat : N 22 ° 07 \
Long : E 48 ° 32 \

The stratigraphy of the study area reaches down from the Quaternary cover through the Neogene and Paleogene into the Cretaceous. The lowermost strata to be identified are those of the Hith Anhydrite. The principal aquifers to be investigated are those of the Umm Er Radhuma limestone, Aruma limestone, Wasia sandstone and Biyadh sandstone.

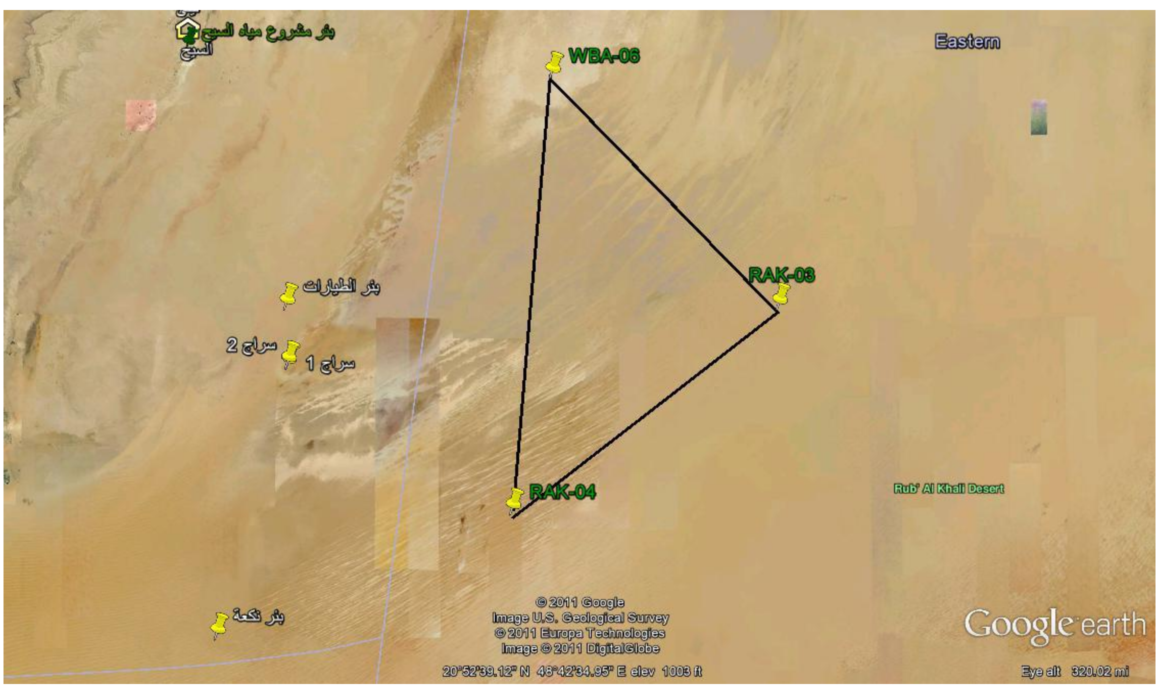


Figure 3. Location map of the study area as determined by the prime contractor.

Work Plan

Task 1 : Preliminary data collection & Evaluation

Before any field work is undertaken in an environment as challenging as the RAK, it is advisable to review existing relevant data, and to carry out a modeling program to gain insight into the detectability, resolution and signature of the various aquifers at various locations. The most relevant information used in MT modeling experiments is the electrical resistivity and thickness of the modeled formations.

Therefore, **Task 1** is to access the ARAMCO (+/- MoWE) wells and other information provided by the prime contractor under suitable terms and conditions. This information will permit construction of suites of "forward models" describing the expected geophysical signature of the stacked aquifers at various locations corresponding to various depths, thicknesses, and salinity. This work does not require extremely sophisticated or powerful computing resources. It is done on a high-end PC with suitable EM "forward modeling" software. While modeling results are not 100% definitive (because they always rely in simplifications) they are useful and instructive.

Task 2 (Field Work)

According to the assigned area by the prime contractor, we plan to set up a grid of several MT parallel profiles to fill the gaps within the triangle. The distance between the two adjacent parallel profiles is 20 km. In each profile, a number of stations will be conducted depending on the length of the profile. The spacing between stations in each profile between 20 and 30 km. The total number of stations is at least 60 stations and the entire field work will be accomplished in 60 days, provided that 1-2 stations to be carried out daily.

Task 3: Analysis and interpretation of data

There is a fairly standard rational succession of interpretation procedures that are followed whenever a magnetotelluric data set is interpreted. These are summarized, in the order they are usually performed, as follows.

- ✓ Qualitative analyses
- ✓ Reformatting, Reprocessing, and Data Correction - if necessary.
- ✓ One-dimensional inversions or forward models - if appropriate.
- ✓ Unconstrained 2-D and / or 3-D inversions or fitted sections - as a first interpretative step in a profile analysis.
- ✓ Constrained two-dimensional inversion - if sufficient geometric constraints (such as an interpreted seismic model or drilling data) exist to justify it.
- ✓ Final trial-and-error refinement of 2-D resistivity models - incorporates available isolated constraints (well logs, surface geology) and most probable geologic hypotheses.
- ✓ Construction of final interpreted geologic model - from refined resistivity section.

Task 4 : Final Report with conclusions & recommendations

MT Deliverables :

Data – printed for each station

Main parameters including:

Apparent resistivity amplitude and phase

Strike and rotation (Impedance, Tipper information)

Dimensionality parameters (skew, ellipticity, tipper magnitude)

Polar Diagrams

Digital data – SEG/EDI format (including the time series)

Station locations

Map and/or digital UTM's (lat/longs)

Description of survey

Gear, personnel, dates, procedures

Problems, processing, noise, etc.

MT field crew

Operators – The Operators are responsible for setting up and tearing down site. They are also responsible for the site location and should attempt to avoid noise sources. They also record the location of the station (via map or gps) and record pertinent information about the station layout.

Field assistants – Assistants aid the operators in carrying and laying/picking up gear. They can be locally hired personnel.

Processor – processes field data. Data are processed after the operators return from the field.

Crew Chief – responsible for general crew ops; oversees all activities

References

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