Qatar Univ, Sci, J. (1997), 17(1) : 143-152

ON THE EFFECTIVENESS OF THE VLF-EM METHOD FOR GROUND WATER PROSPECTING IN THE BASEMENT TERRAINS, SINAI, EGYPT

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حول فاعلية طريقة الموجات الكهرومغناطيسية ذات التردد المنخفض جداً للتنقيب عن المياه الجوفية في صخور القاعدة ، سيناء ، مصر

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لقد أثبتت الدراسات والأبحاث السابقة ان استخدام طريقة المقاومة الكهربائية للتنقيب عن المياه الجوفية في المناطق التي تتميز بالمناخ القارى الجاف تعاني من صعوبة في تنفيذ العمل الحقلي وذلك لصعوبة اختراق التيار الكهربائي لطبقة الرواسب السطحية ذات المقاومة الكهربية المرتفعة. لذلك فان هذا المناخ القارى يمثل بيئة ملائمة لاستخدام طريقة الموجات الكهرومغناطيسية ذات التردد المنخفض جداً للتنقيب عن المياه الجوفية بالاضافة الى أنها طريقة سريعة التنفيذ في الحقل ومنخفضة التكاليف.

وقد تم بنجاح استخدام طريقة الموجات الكهرومغناطيسية ذات التردد المنخفض جداً (١٥ – ٢٥ كيلو هرتز) للتنقيب عن المياه الجوفية في رواسب الوديان التي تخترق صخور الركيزة المعقدة بجنوب سيناء، مصر. وقد ساعدت المقاومة الكهربية المرتفعة للطبقة السطحية من رواسب الوديان على اختراق الوجات الكهرومغناطيسية المستقبلة لأعماق تتعدى خمسون مترا تحت سطح الأرض لتصل بسهولة الى طبقة رواسب الوديان المحملة بالمياه الجوفية حيث تم تحديد التغيرات الجانبية في قيم مقاومتها النوعية ومن ثم تحديد أنسب الأماكن لحفر آبار مياه. وقد تم تأكيد النتائج باجراء بعض الجسات الكهربية الراسية.

Key Wards : VLF - EMMethod, Graund Water, Sinai.

ABSTRACT

The VLF-EM method is proved to be an effective, fast and inexpensive tool for ground water prospecting in the basement terrains of Southern Sinai. The resistive shallow alluvial deposits increase the penetration depth of the received VLF waves to as deep as 40 meters which is very reasonable to detect the water bearing alluvium in the studied areas. The measured horizontal and vertical components of the resultant VLF-EM field were used to calculate the apparent resistivities of the conductive alluvial deposits. D.C. resistivity soundings were, therafter, carried out at some selected sites to confirm the VLF-EM anomalies and to decide the best Sites for drilling water wells.

INTRODUCTION

The Pre-Cambrian basement rocks cover a vast area in southern Sinai that is dissected by major wadis in which the local Bedouins strongly depend on ground water for their daily requirements. Therefore, locating water well sites in this environment is of prime interest. From different geophysical methods, the galvanic resistivity sounding has proved to be a successful technique for determining layered earth materials and is routinely employed for investigating properties of the weathered layer in basement terrains. However, this method suffers from drawbacks such as its high cost and relative slowness. Moreover, the contact resistance of electrodes is often too high and affects the reliability of the measurements due to the high electrical resistivity of the alluvial deposits at shallow depths. Accordingly, looking for an inexpensive and fast geophysical method is extremely demanded to determine the overburden parameters in this environment. The VLF-EM method can offer this advantage because of the following reasons:

a- The measuring device is light and normally operated by one person.

b- Readings are extremely rapid and the power consumption is negligible.

c- The operation is so simple that unskilled personnel can be trained as operators in a matter of hours.

d- The method is capable of exploring to reasonably large depths in non-conductive rocks.

In the present article, the VLF-EM method is tested in two areas of basement rocks in southern Sinai. The obtained results are, thereafter, confirmed by D.C. resistivity soundings.

GENERAL REVIEW OF THE VLF-EM METHOD

Electromagnetic prospecting methods, in general, rely on the measurements of secondary fields that are generated by conducting bodies, such as water bodies and metallic minerals, in the ground when subjected to primary electromagnetic signals. The VLF-EM method employs the primary signals from powerful military radio transmitter stations distributing throughout the world and working in the 15 to 25 KHz radio band for long range communications and navigational system. The electromagnetic waves propagate through the subsurface and are subjected to local distortions by conductivity contrasts in this medium. These distortions indicate variations in geoelectrical properties which may be related to the presence of ground water. The subsurface occurrence of these conductive bodies create a local secondary field which has its own components. Measurements of these components may permit locating the subsurface conductive zones [1,2]. The primary electromagnetic waves contain both electric and magnetic components and travel in three modes which are: sky wave, space wave and ground wave [3]. At large distances from the transmitters we are concerned with the sky wave which is guided by the ionosphere and the earth surface. The depth of penetration of these waves depends on their frequencies and the electrical conductivity of the ground. This depth thus increases as both the wave frequency and the ground conductivity decrease according to the following relation:

$$\delta = \sqrt{\frac{2}{\mu_o \sigma \omega}} \cong 500 / \sqrt{\sigma f} \qquad (1) \quad [4]$$

Where:

δ = Skin depth in meter (i.e. the depth of penetration of a wave passing into a conductor in which the amplitude of the wave is attenuated to 1/e of its amplitude at the surface of the conductor),

μ_o = Magnetic permeability of free space = $4\pi \times 10^{-7}$ Henrys/m.

ω = Angular frequency ($2\pi f$)

σ = Electrical conductivity of earth materials in mho/m.

f = Signal frequency (Hz)

Practically, an effective depth of penetration (Z_e) of the VLF-EM field can be defined as the maximum depth at which a conductor may lie and still produce a recognizable electromagnetic anomaly and is given by the following relation:

$$Z_e = 100\,(\sigma f)^{-1/2} \quad (2)\ [5]$$

The VLF-EM instrument is a directional radio receiver which can be tuned to distant radio transmitters. Some receivers are designed to measure the magnetic component of the VLF-EM waves and others are used to detect the electric component. Beneath the ground surface, the magnetic component carries the bulk of the signal energy.

GENERAL GEOLOGY AND HYDROGEOLOGY OF THE STUDIED AREAS

A- Wadi Solaf area:

Wadi Solaf is one of the three major tributaries of Wadi Feiran, Southern Sinai Fig.1 and forms a separate hydrogeologic basin. It receives a huge amount of surface water, annually, in the form of floods. A reasonable number of Bedouin families live in this wadi. They depend mainly on the ground water to cover their daily requirements.

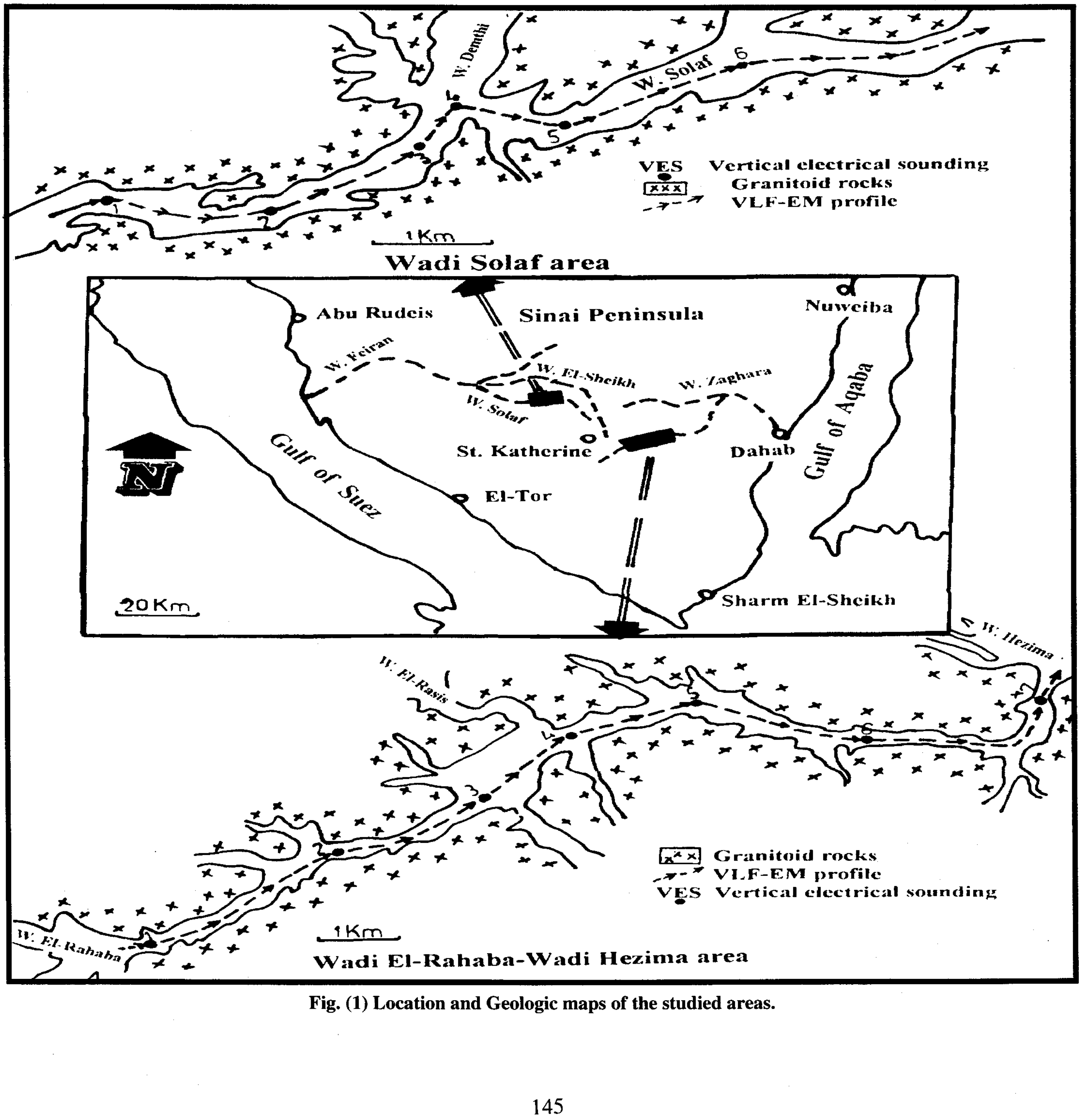

Fig. (1) Location and Geologic maps of the studied areas.

The studied part of Wadi Solaf was chosen according to the following reasons:

a- Near the Bedouin settlements and activities.

b- The presence of many drainage lines and structural lineaments.

c- Relatively low surface gradient (5m/Km) which facilitates the vertical percolation of surface water and feeding the ground water aquifer.

Geologically, this part of Wadi Solaf is covered by granitoid rocks, dissected by dykes of different composition [6,7]. The main stream of the Wadi is filled by alluvial deposits, consisting of boulders and gravels mixed by finer clastics.

B- Wadi El-Rahaba - Wadi Hezima area:

It is a part of the main branch of Dahab basin and drains eastwards to the Gulf of Aqaba (Fig.1). The area is covered by granites, granodiorites, diorites and monzonites which show fracture systems with different degrees. The Wadi course is filled by alluvial deposits with high hydraulic conductivity [8].

In both areas, the ground water occurs in the alluvial deposits and the underlying fractured basement rocks. It is mainly recharged from the surrounding fractured basement rocks, rain fall and snow. The water quality showed low total dissolved salts, rarely exceeds 1000 mg/l.

FIELD SURVEYING

The VLF-EM measurements were carried out along profiles, running parallel to the main courses of the studied wades (Fig.1). The profile length of Wadi Solaf was 5.9 Km while that of Wadi El-Rahaba-Wadi Hezima area was 11 Km. long. The station interval was 40 m. in Wadi Solaf and 100 m. in the other area. The field readings were taken by using the SCOPAS SE-81 VLF receiver (single coil-phase, amplitude and strike receiver). This device was designed to measure the components of the magnetic part of the VLF field. It is a small hand-held instrument incorporating two orthogonal aerials which can be tuned to the particular frequencies of the transmitters. The direction of a transmitter is found by rotating the horizontal instrument around a vertical axis until a null position is found. Then the maximum horizontal component is measured by rotating the receiver in the horizontal plane until a maximum signal is observed on the meter. Rotate the SCOPAS upward through 90^o while the face of the unit is toward your body and note the amplitude of the vertical component of the secondary VLF-EM field [9].

At the studied areas in southern Sinai, it was possible to receive the VLF radio signals from both the North west Cape (NWC) station, Australia with a frequency of 15.5 KHz and radiating power of 1000 KW and Sainte Assise station (UFT), France with a frequency of 20.7 KHz and radiating power of 61 KW. The signals from these transmitters were strong and clear enough for reliable measurements. At every station along the measured profiles, the horizontal and vertical components (Hx and Hz) of the magnetic part of the VLF field were recorded.

After representing and interpreting the VLF measurements, it was decided to carry out a number of vertical electrical sounding for the sake of confirming the VLF anomalies, determining resistivity and thickness distribution in the subsoil and to decide the best sites for drilling water wells. Six soundings were measured along the studied part of Wadi Solaf and seven along Wadi El-Rahaba-Wadi Hezima area (Fig.1). Schlumberger electrode configuration were applied in all soundings where the current electrode distance was 400 meter which is long enough for the electric current to penetrate the alluvial deposits and their underling weathered basement to reach the solid basement rocks.

PROCESSING AND INTERPRETATION OF THE VLF-EM MEASUREMENTS

The apparent resistivity (ρa) of the subsurface alluvial deposits in the studied areas could be calculated from the measured horizontal (H_x) and vertical (H_z) components of the received secondary VLF-EM wave by applying the following formulas:

$$\left|\frac{Hx}{Hz}\right| = \sqrt{\frac{\mu_o}{\varepsilon_o}} \frac{10^2}{\sqrt{8\pi^2 f}} \frac{1}{\rho a} \quad (3) \text{ .... [10,11]}$$

Where:

μ_o = Magnetic permeability of the free space ($4\pi \times 10^{-7}$ Henerys/m),

ε_o = Dielectric constant of the free space (8.85×10^{-12} Farady/m),

f = Frequency of the received VLF wave in kHz.

The total longitudinal conductance (S) of these deposits could also be calculated by applying

$$\left|\frac{Hx}{Hz}\right| = \sqrt{\frac{\mu_o}{\varepsilon_o}}\ S \qquad (4) \text{ .... [11]}$$

In the basement environment, (S) value is determined by the relation between the total thickness H of the alluvial deposits overlying the basement bedrock and their bulk resistivity ρ (i.e. S = H/ρ). This means that increase in the value of S from one point to the next indicate an increase in total thickness of the alluvium, a decrease in resistivity, or both. On the other hand, the depth to the top of the conductive alluvium (Z_c) could be estimated from the measured VLF components by applying

$$Zc = 10^2 \sqrt{\frac{\rho a}{8\pi^2 f}} \qquad (5) \text{ .... [11]}$$

where

ρa = apparent resistivity in Ωm,
f = wave frequency in kHz.

The calculated values of both the apparent resistivity, the total longitudinal conductance and the depth to the conductive alluvial deposits are smoothed by moving average technique using weight of the five successive points of observation in order to eliminate very short period scatter of the measured values. The smoothed values are then presented in the form of profiles for each area.

General inspection of the VLF apparent resistivity profile along the studied part of Wadi Solaf (Fig.2) shows that the calculated values are ranging between 50 and 300 Ωm. Depending on our knowledge and experience in the exploration for ground water in the basement terrains of southern Sinai with the D.C. resistivity method [12, 13], these values are related to water bearing alluvial deposits.

The relative variations in the resistivity values are due to the degree of water saturation as the lithology of the alluvium and water quality remain constant along the wadi course. However, some high resistivity values which may reach to as high as 1000 Ωm are detected between measuring stations 75 and 95 Fig. 2 . These values are believed to be due to basement rocks at shallow depths which may play a considerable role in damming and accumulating the ground water in the alluvial deposits in the lower part of the wadi (i.e. between stations 30 and 70). This is clear from the average resistivity value of the alluvial deposits in this part of the wadi (≅150 Ωm) which is lower than that of the alluvial deposits in the upper part of the wadi (i.e. from station 100 to the end of the profile). From that, it could be concluded that the alluvial deposits in the lower part of the wadi is more saturated with ground water than that of the upper part and any drilling activities should be

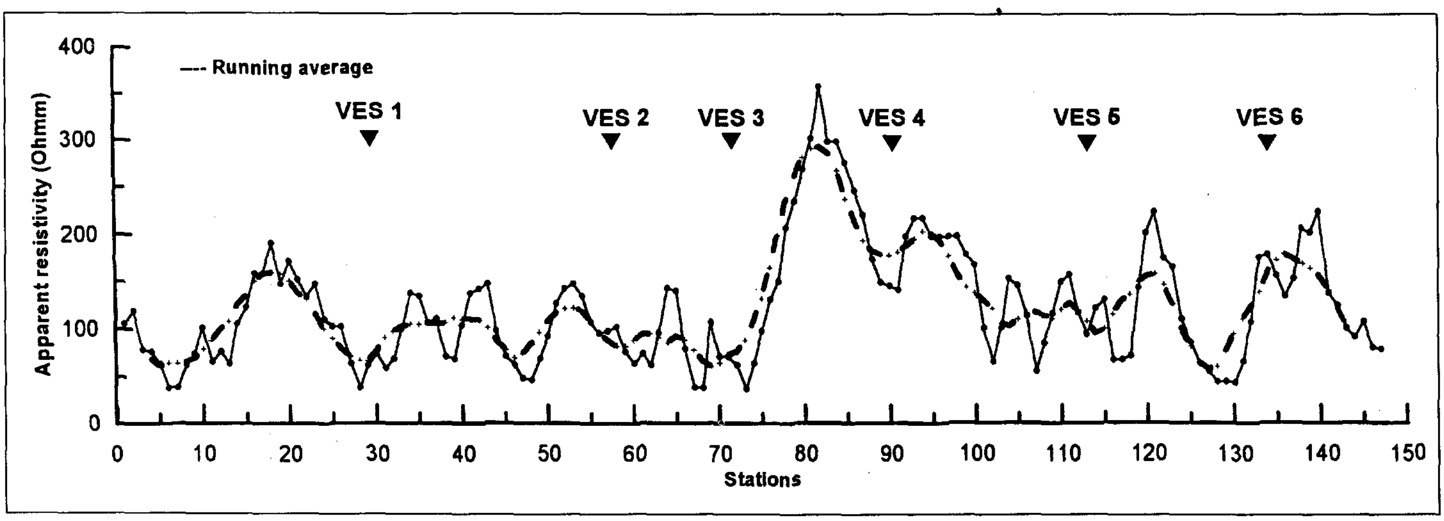

Fig. (2) : Apparent resistivities of alluvium in Wadi Solaf as deduced from the VLF-EM.

directed to the lower part. This conclusion is confirmed by the profile of the longitudinal conductance (Fig.3) which shows an average value higher in the lower part ($\cong$ 0.040 Ω^{-1}) than in the upper part ($\cong$ 0.030 Ω^{-1}). On the other hand, the water bearing alluvial deposits in Wadi Solaf occur at depths ranging between 17 and 54 m below ground level (Fig.4).

The VLF apparent resistivity profile along the area of Wadi El-Rahaba-Wadi Hezima shows that the smoothed values vary between 50 and 150 Ωm somewhat less than those of Wadi Solaf (Fig.5). These values are again related to conductive alluvial deposits and the resistivity variations are due to the degree of water saturation. It is also noticed that the average resistivity value in the middle part of the profile ($\cong$ 100 Ω m) between stations 50 and 85 is lower than those of the upper and lower parts of the profile ($\cong$125Ωm). This means that any further evaluation of ground water should be directed towards the middle part of the wadi. The geological map of the area (Fig.1) confirms this conclusion as there is a considerable number of drainage lines draining in this part of the wadi and feeding the ground water. Also the total longitudinal conductance profile of the area gives a clear picture about the conductivity variations of the alluvial deposits (Fig.6) as there is a direct relation between the Svalues and the alluvium conductivities. Applying equation (5), the depth of the conductive alluvial deposits in the area of W.El-Rahaba-W.Hezima ranges between 17 and 36 meter below ground surface (Fig.7).

CONFIRMATORY EVIDENCE

This is the first time that the VLF-EM method was used for ground water prospecting in the basement terrains of Egypt. Therefore, the obtained results were checked by another well-known geophysical method in the field of hydrogeophysics, namely The D.C. resistivity method. this

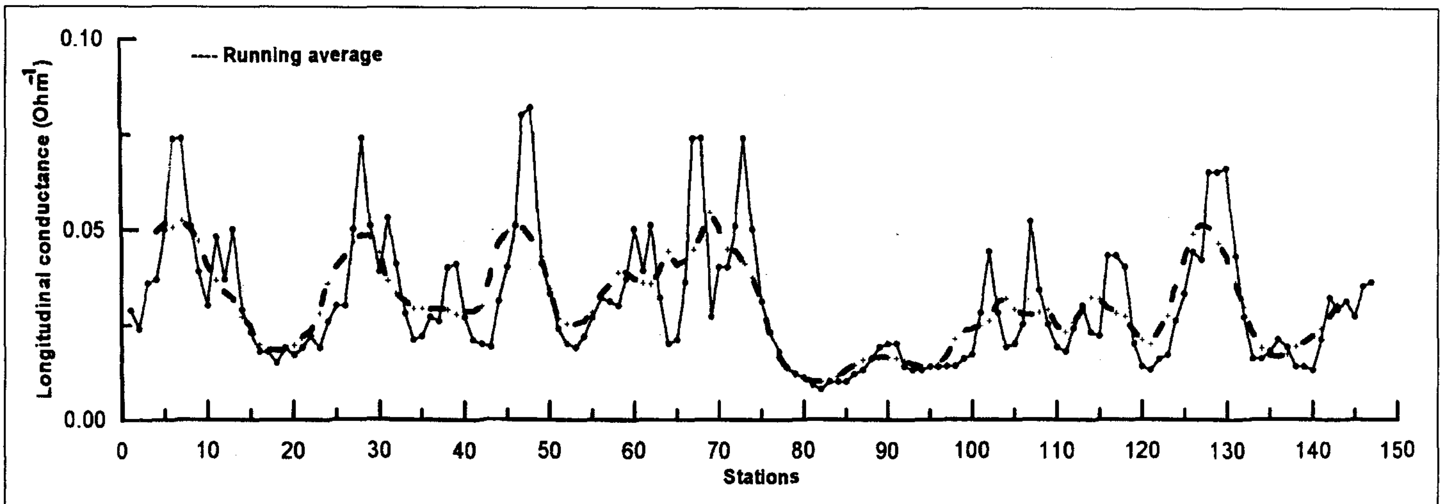

Fig. (3) : Total longitudinal conductance of alluvium in Wadi Solaf as deduced from the VLF-EM.

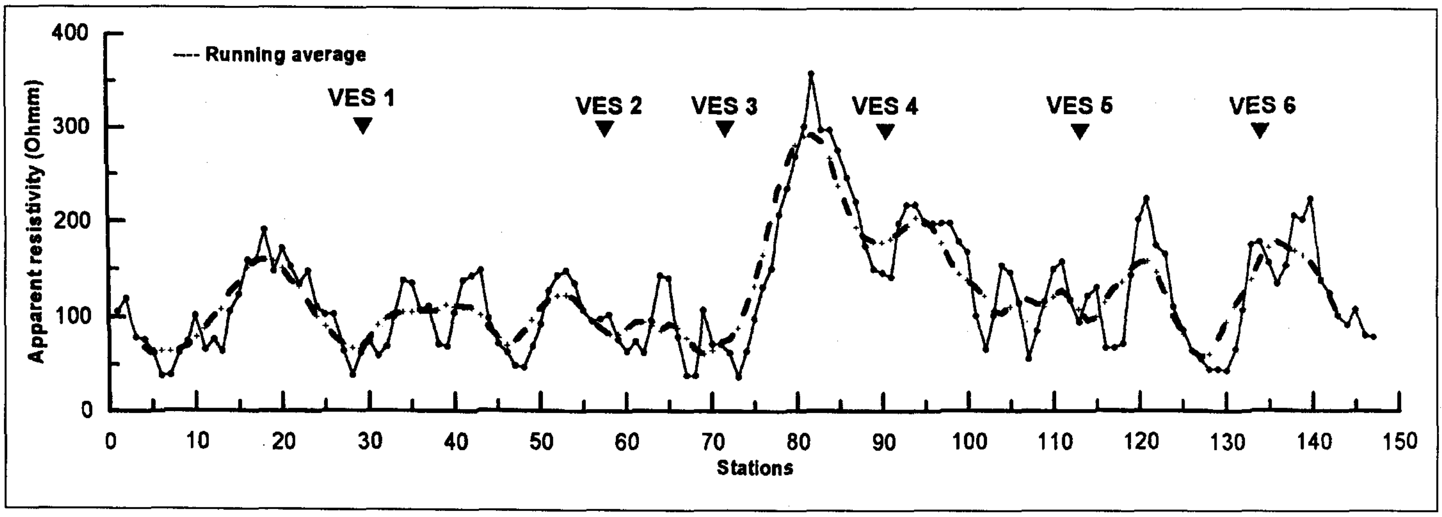

Fig. (4) : Depths to conductive alluvium in Wadi Solaf as deduced from the VLF-EM measurements.

among the most popular geophysical tools for ground water exploration in the different geological environments due to its adaptability to a large range of depths of investigation. Accordingly, six vertical electrical soundings (VES) have been carried out in some selected sites in the studied part of wadi Solaf. Three of them were located in the low VLF resistivity zone (i.e. VES 1,2 &3) and two are executed in the high resistivity zone (i.e. VES 5 & 6) whereas the sounding number 4 was measured above the expected shallow subsurface basement intrusion (Fig.2). This distribution of soundings was believed to cover the different subsurface hydrogeological conditions in the studied wadi. In the area of wadi El-Rahaba-wadi Hezima, seven soundings were carried out to cover also the different geological conditions (Fig.5).

The data from the thirteen Schlumberger soundings in the two studied areas were analyzed manually by using master curves of Mundry et.al. [14] as well as automatically by computer software of Velpen [15] Taking into account the studied areas and based on our experience in prospecting ground water in the basement terrains of southern Sinai, one could guess that the appropriate subsurface model should have four geoelectrical layers which, from top to bottom, are: dry alluvial deposits, water bearing alluvium, water bearing weathered and fractured basement rocks and solid basement rocks [12 & 13]. The water bearing alluvium and the underlying fractured basement rocks will constitute the main ground water aquifer where the discrimination between the different locations should rely on the thickness and resistivity of this aquifer.

The geoelectric section along Wadi Solaf (Fig.8) shows that the location of VES 3 is the best site for drilling water well because of the following reasons:

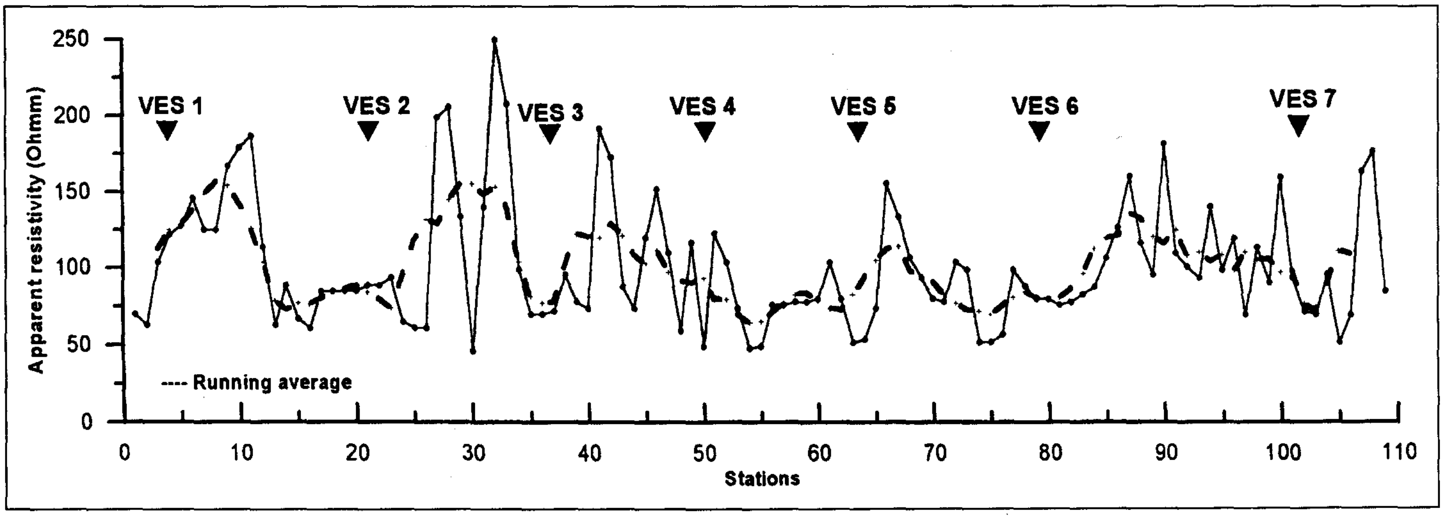

Fig. (5) : Apparent resistivities of alluvium W.El-Rahaba-W.Hezima as deduced from the VLF-EM.

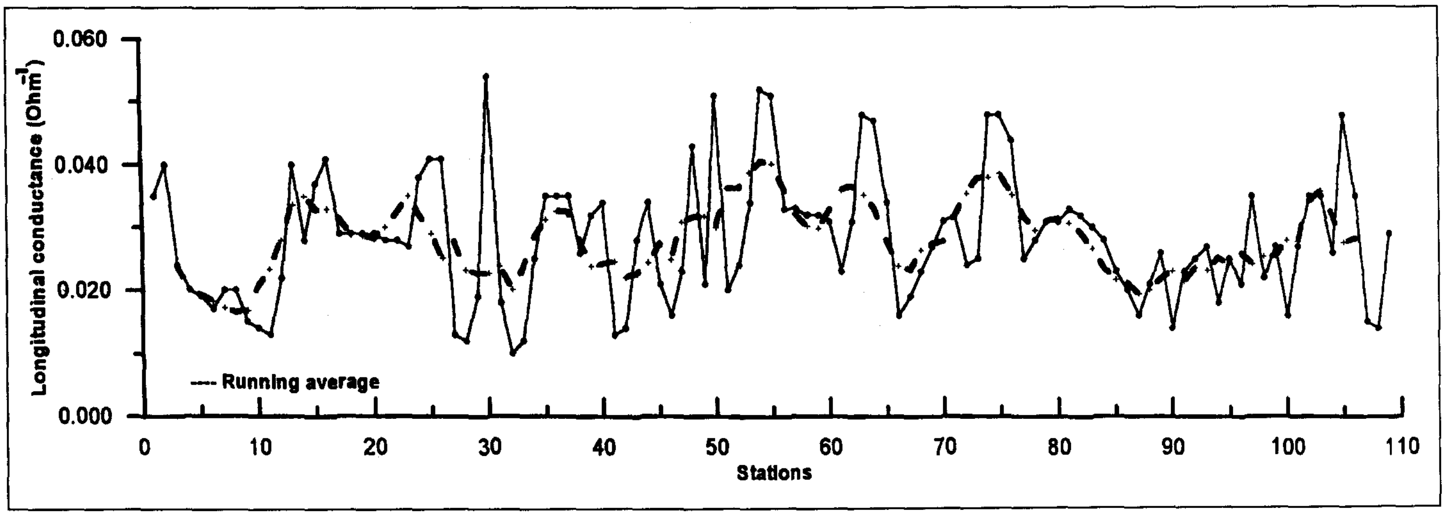

Fig. (6) : Total longitudinal conductance of alluvial deposits in W.El-Rahaba-W.Hezima area as deduced from the VLF-EM.

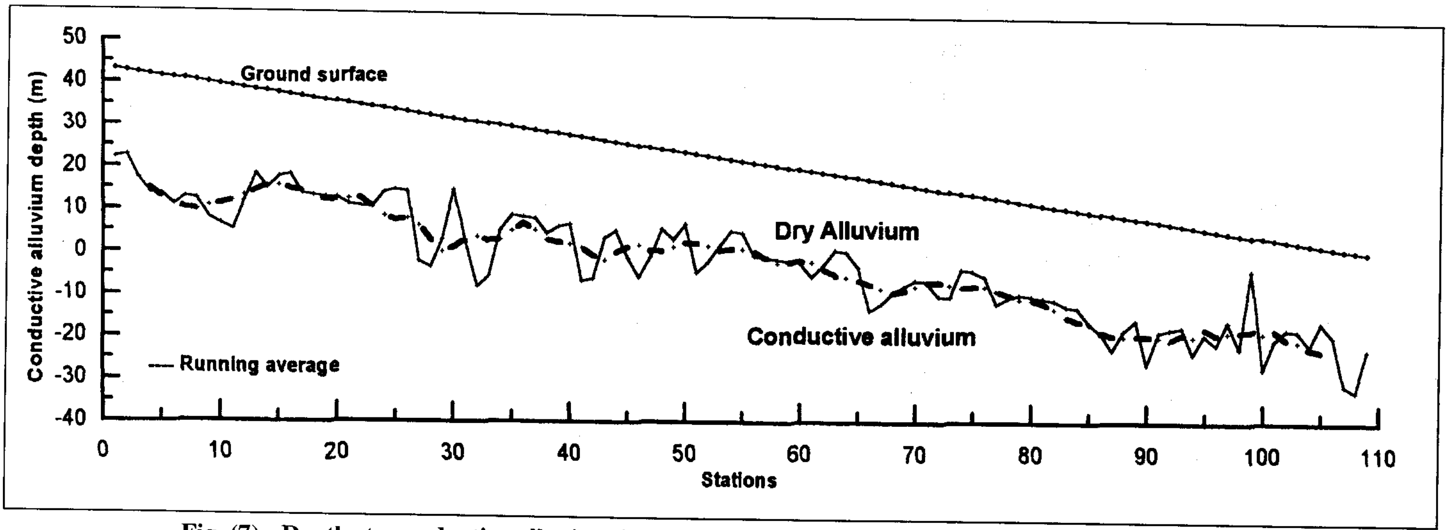

Fig. (7) : Depths to conductive alluvium in W.El-Rahaba-W.Hezima as deduced from the VLF-EM.

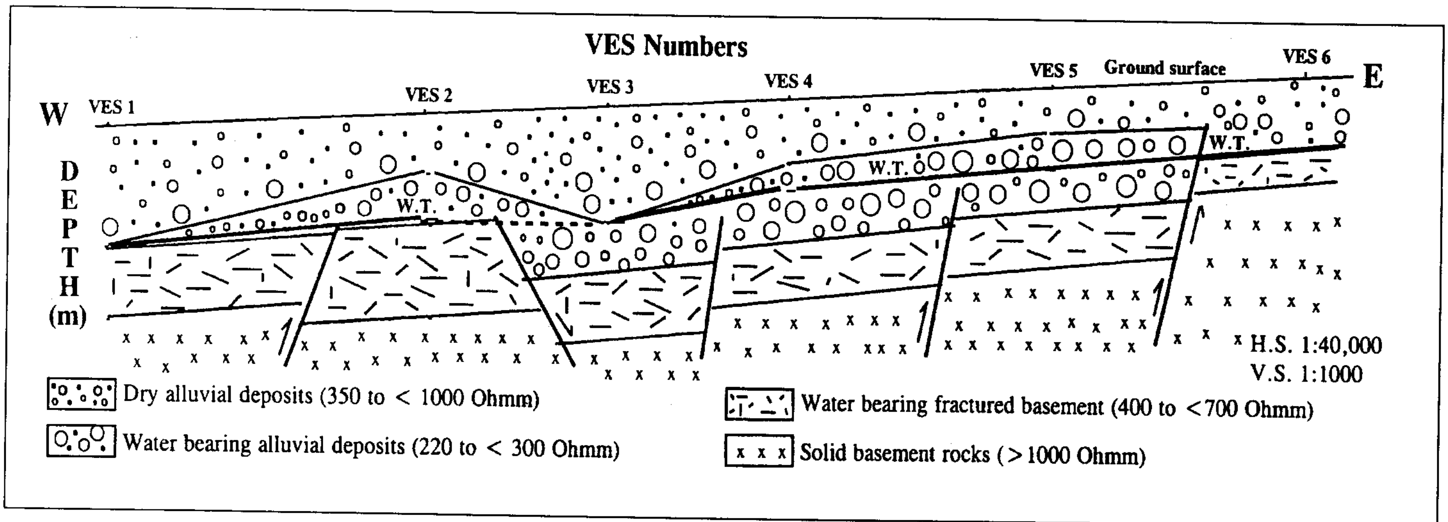

Fig. (8) : Geoelectric section along the studied part of Wadi Solaf.

a- The great thickness of water bearing alluvial deposits and of the fractured basement.

b- The occurrence of basement rocks at shallow depth close by (VES 2) which may act as subsurface barrier for ground water.

c- VES 3 is located at the extension of W.Demthi-major (Fig. 1). This is an ideal condition for ground water accumulation because the weathering will be deeper than in the surroundings and the thickness of the thickness of water column will be higher.

This conclusion agrees well with that obtained from the VLF-EM measurements where the location of VES 3 is characterized by low resistivity value (≅ 50 Ωm, Fig.2).

On the other hand, the geoelectrical section of the Wadi El-Rahaba - Wadi Hezima profile (Fig.9) shows that here again the location of VES 3 is the best site for drilling water well for the following reasons:

a- The great thickness of the water bearing alluvium and weathered basement rocks.

b- The occurrence of the solid basement rocks at shallow depth below VES 4 act as a barrier against water run-off.

c- VES 3 lies at the intersection of two major faults (Fig.1) which constitute favorable conditions for ground water accumulation.

Although, the alluvial deposits at VES 5 seems to be dry, this site comes in the second priority for drilling a water well because of the great thickness of the water bearing

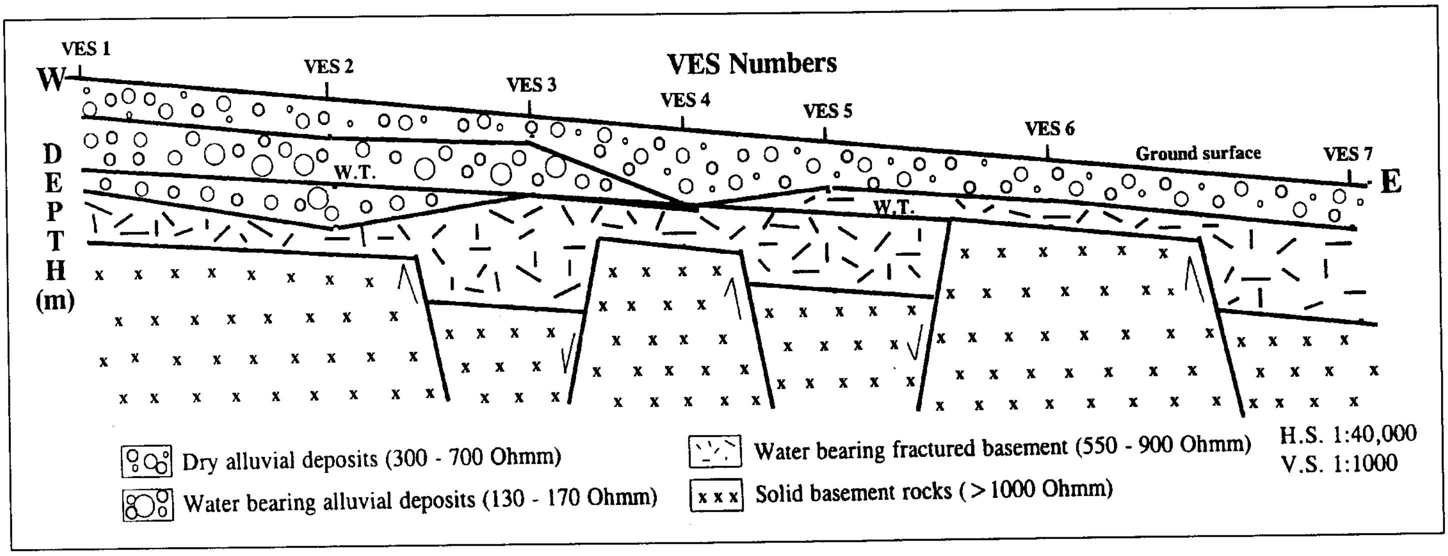

Fig. (9) : Geoelectric section along W.El-Rahaba - W.Hezima area.

weathered and fractured basement and the intrusion of solid basement below VES 6 which control the ground water movement here.

CONCLUSION

The VLF-EM method has been used successfully for ground water exploration in the alluvial deposits of the basement terrains in southern Sinai. The presence of dry and resistive surfacial alluvial deposits increases the penetration depth of the VLF-EM waves for a few tens of meters to reach the conductive alluvium. In the arid and semiarid environment, it is difficult to carry out D.C. resistivity surveying due to the difficulty in injecting electric current through the grounded electrodes. Therefore, the VLF-EM method provides a fast and inexpensive tool for mapping the conductive alluvial deposits in basement terrains. It is also recommended that the VLF-EM results should be verified by another geophysical method, effective in ground water exploration.

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