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GEOPHYSICAL EXPLORATION FOR GROUNDWATER POSSIBILITIES IN WADI EL- RAHBA, EASTERN DESERT, EGYPT

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استكشاف جيوفيزيائى لإمكانيات تواجد المياه الجوفية بوادي الرحبة بالصحراء الشرقية – مصر

الخلاصة: تقع منطقة الدراسة فى الجزء الجنوب الشرقى من الصحراء الشرقية وتشمل المجرى الرئيسى لوادى الرحبة الذى يصب فى البحر الأحمر على بعد ٤٠ كم شمال مدينة الشلاتين. الغرض من الدراسة هو تقييم إمكانياتها من المياه الجوفية ومن ثم تحديد أفضل المواقع لحفر آبار للمياه. ولتحقيق ذلك فقد تم عمل مسح كهربى بطريقتى الجسات الكهربية الرأسية (١٤ جسة)، والكهربية ثنائية الأبعاد (ثلاث بروفيلات) والسيزمية الانكسارية الضحلة (بروفيلين).

وبتحليل نتائج القياسات الجيوكهربية باستخدام برامج الحاسب الآلى الحديثة تبين أن التتابع الجيوكهربى يتكون من أربع طبقات بالإضافة إلى الغطاء السطحى. وتتكون هذه الطبقات من رواسب العصر الرباعى والتى تتمثل فى رواسب الوديان الجافة تليها إلى الأسفل صخور القاعدة المتشققة المشبعة بالمياه وأخيراً صخور القاعدة الجافة الغير المشققة. وقد بينت النتائج أن المياه الجوفية تتواجد فى كل من رواسب الوديان وصخور القاعدة المشققة. وبينما يتواجد كلا النوعين من الخزانات بسمك إجمالى يبلغ عشرة أمتار فى الجزء السفلى من الوادى (مواقع الجسات ٨، ٩، ١٠، ١١) فأن النوع الثانى فقط من الخزانات هو الذى يوجد أعلى الوادى (مواقع الجسات ١، ٢، ٣، ١٣، ١٤) بسمك يتراوح بين ثلاثة وخمسة أمتار. أما الجزء الأوسط من الوادى (مواقع الجسات ٤، ٥، ٦، ٧) فتختفى عنده المياه الجوفية نظراً لوجود فالقين يحصران بينهما كتلة مرتفعة صاعدة من صخور القاعدة. وحيث أن الطريقة السيزمية لم تتوصل إلا إلى عمق ٣٠ متراً فقط فإنها لم تساهم بشىء يمكن إضافته إلى ما تم استنتاجه من خلال الطرق الجيوكهربية.

ABSTRACT: *The concerned area has been geophysically studied applying the techniques of Vertical Electrical Sounding, Electrical Resistivity Imaging and refraction seismic. The aim of this study is to evaluate the groundwater conditions along the main channel of Wadi El Rahba. The geoelectrical resistivity survey includes 14 vertical electrical soundings and three 2-D resistivity imaging profiles. The subsurface succession downward consists of dry wadi deposits composed of gravel, sand, fine sediments and rock fragments as well as two water-bearing layers, the first layer is composed of wadi deposits and the second is composed of fractured basement rocks and the last formation is highly resistive layer massive basement rocks.*

The results of interpretation revealed that downstream of wadi El-Rahba, two water bearing layers exist, an upper layer consisting of wadi deposits and an underlying layer consisting of fractured basement. Upstream of wadi the only water bearing layer is that of fractured basement. The results showed also that the basement reliefs as well as intersecting faults control the groundwater occurrences in the area. It was concluded that the promising parts of the area as to groundwater occurrences are those covered by VES station 1 to 3 and 8 to 12, where groundwater was detected at a depth of 40 –60m.

INTRODUCTION

Wadi El Rahba lies in the southern part of the Eastern Desert of Egypt, between longitudes 35° 05'-35° 35' E and latitudes 23° 08' - 23° 35' N (Figure 1). It includes one of the promising areas of the Eastern Desert as to the future sustainable development in the fields of land reclamation, animal production and tourism. The area faced a serious drought period that strongly affected the daily life of the nomadic community living there . So, it was highly recommended to carry out geophysical and hydrogeological studies in the area with purpose of exploring its groundwater possibilities.

The main objective of the present geophysical work is to study the subsurface layering in terms of the lithologic variation of the encountered rock succession and hence to delineate the subsurface geologic condition including the occurrence of aquifers and the affecting structures. This would lead help in locating the best suitable sites for the drilling of water wells.

To achieve these objectives, the following steps were followed up: (1) Reviewing the available previous information about the geomorphology, geology and hydrogeology of the area, (2) carrying out a detailed geophysical survey, (3) interpretation of the field measurements and presentation of the reached results.

GEOMORPHOLOGICAL, GEOLOGICAL AND HYDROGEOLOGICAL SETTINGS

Few regional studies related to the geology, geomorphology and water resources were carried out in the region including the study area by Omar (2000), Aglan (2002), and Baraka (2002). However, no geophysical studies were carried out in Wadi El Rahba.

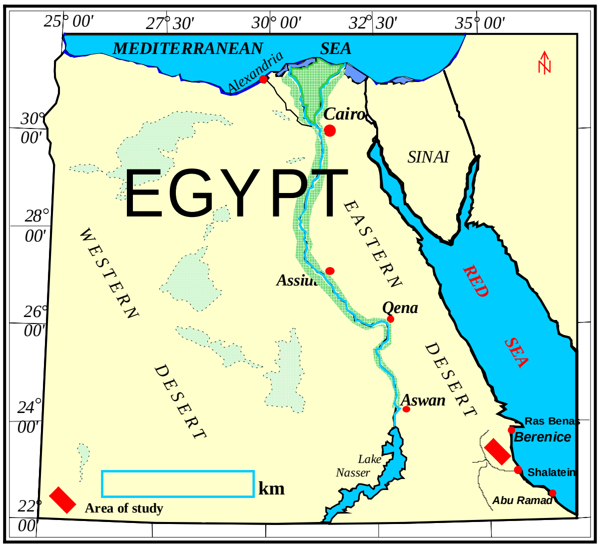

Fig. (1): Geographic situation of the study area.

The study area lies within the south eastern part of the Eastern Desert where the climate is characterized by extreme aridity with low and erratic rainfall; sometimes with flash floods, high evaporation rates, high summer temperature and generally vigorous winds.

A- Geomorphology:

Wadi El Rahba drains from Gebels El Farayid (+1366m.a.s.l.), Medarai (+1299 m.a.s.l.) and Abu Dahr (+1131m.a.s.l.), curves round to the south of Gebel Fareiyid and proceeds nearly due to east to reach the Red Sea at about latitude 23^0 12', after receiving some tributaries in its way such as Wadi Titai, Wadi Abu Reye, Wadi Abiad, Wadi Megah and Wadi Marafai. The upper part of wadi El-Rahba contains many trees and bushes but the lower parts are approximately barren. Its total length is about 75 km. The upper part (25 km) has an average slope of 8m/km, where the lower part is narrow Shabana et al., (2003).

The investigated area is built mainly of six units as follows:

1. The Red Sea basement mountains built up of igneous and metamorphic rocks; they represent the catchment area of groundwater recharge for the aquifer in the area.
2. The inland tectonic depressions, oriented in a NW-SE direction parallel to the Red Sea (represented by two plains). They are developed along grabens following the prevailing tectonic elements.
3. The Pediment plain, characterized by a large plain that reaches about 15km in width and its elevation ranges from (about 100m) in the west to the sea level in the east.
4. The Tertiary volcanics, lying between the mountainous area and the piedmont plain which are crossed by extrusive volcanic rocks of differing rock composition (ryohlite, basalt, dolerites, etc) through parallel fault system. They form a discordant zone extending in a NW direction.
5. The Coastal plain, comprising many different sub-geomorphologic units as sand sheets to the west and sabkha in the east.
6. The Hydrographic drainage basin, that drains from the catchment area along the Red Sea mountains into the Red Sea to the north of El Shalatein area. It occupies a surface area of about 980 km^2. It is built up mainly of Late Proterozoic basement rocks. It has a vital importance due to the presence of El Gahelia well, which represents the main source of fresh water suitable for drinking for El Shalatein area.

B- Geologic Setting:

Wadi El-Rahba basin occupies an area of about 1047 km^2, covered by basement rocks and wadi deposits. The Precambrian rocks comprise Pre-Pan African, Ophiolitic and Island Arc assemblages and Early to Post Magnetic units (Ramadan, 1994). Tertiary basaltic intrusions present in the piedmont plain in front of Wadi El-Rahba outlet. Alluvial wadi deposits represent the Quaternary deposits. Sand sheets, sand dunes and alluvial fans occupy the Red Sea coastal plain (Fig. 2).

According to the geologic map (Conoco 1987), the study area is structurally affected by some faults and folds that affecting the basement rocks. The most important structural elements which affecting the groundwater occurrences are faults, fractures and dykes.

C- Hydrogeological Setting:

The groundwater is available from two main aquifers; the Quaternary (alluvium) aquifer and the Precambrian (fractured basement rocks) aquifer. The basement rocks consist of older granitoides, granites, gneisses and migmatites, schists, metasediments, gabrodiorites and quartzites. The processes for locating water accumulation in fractured basement rocks depend on studying carefully the surrounding structural elements, especially orientation, size and density of the intrusive dykes, which act as a damming feature to the percolated water, as in Bir Gahelia in the upper portion of Wadi-El Rahba, which is strongly controlled by dykes Shabana et al., (2003).

Several hand-dug wells are present in the vicinity of the wadi, at the junction point tributaries (the point of intersection tributaries, i.e. Bir Abu Raya), Water collection from some of wells is at the mostly controlled by dykes as of Bir Gahelia. These wells are productive ($1m^3$/hr.) Shabana et al., (2003) and of very good water quality.

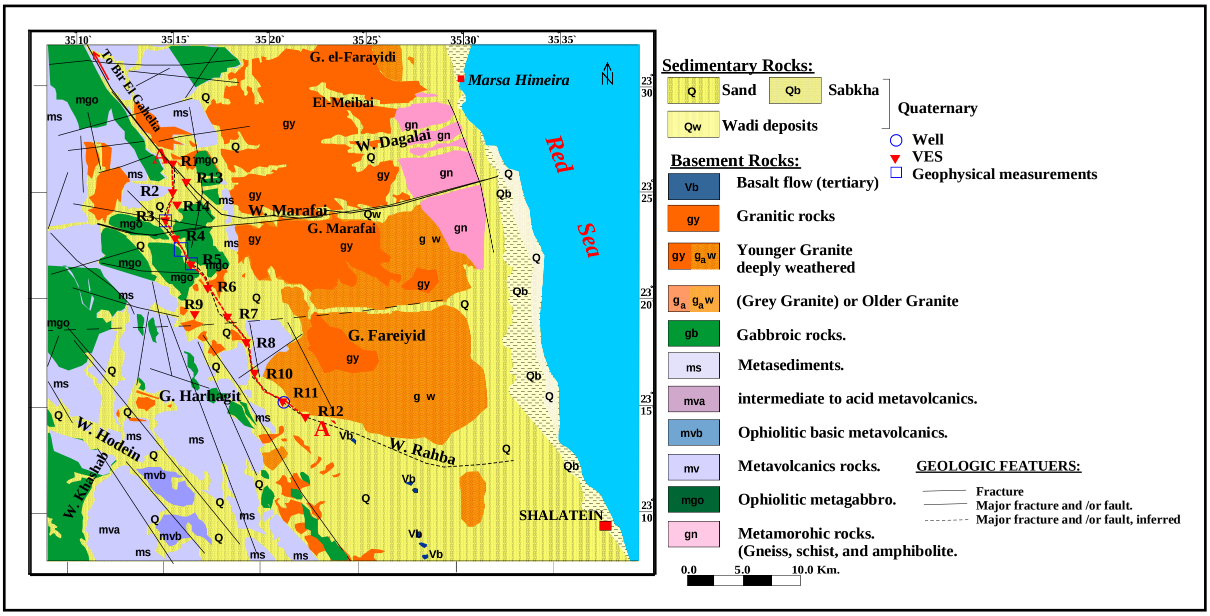

Fig. (2): Geologic map of Wadi El Rahba and its vicinities (After Conoco 1987, original scale 1:500,000).

FIELD WORKS AND INTERPRETATION TECHNIQUES

In this study, the shallow geophysical measurements including the geoelectrical resistivity (Vertical Electrical Sounding, (VES), electrical resistivity imaging survey (tomography) and the shallow refraction seismic techniques are used and measured along the main channel of Wadi El Rahba as shown in Fig. 3.

1- Field Geophysical Techniques:

The work involved the use of three of the geophysical techniques used in shallow subsurface investigation, namely, Vertical Electrical Sounding (VES), 2-D electrical imaging (electrical tomography) and refraction seismic. Field measurements were carried out along the main channel of wadi El-Rahba as shown in Figure (3). The application of each of the techniques used is briefly given below:

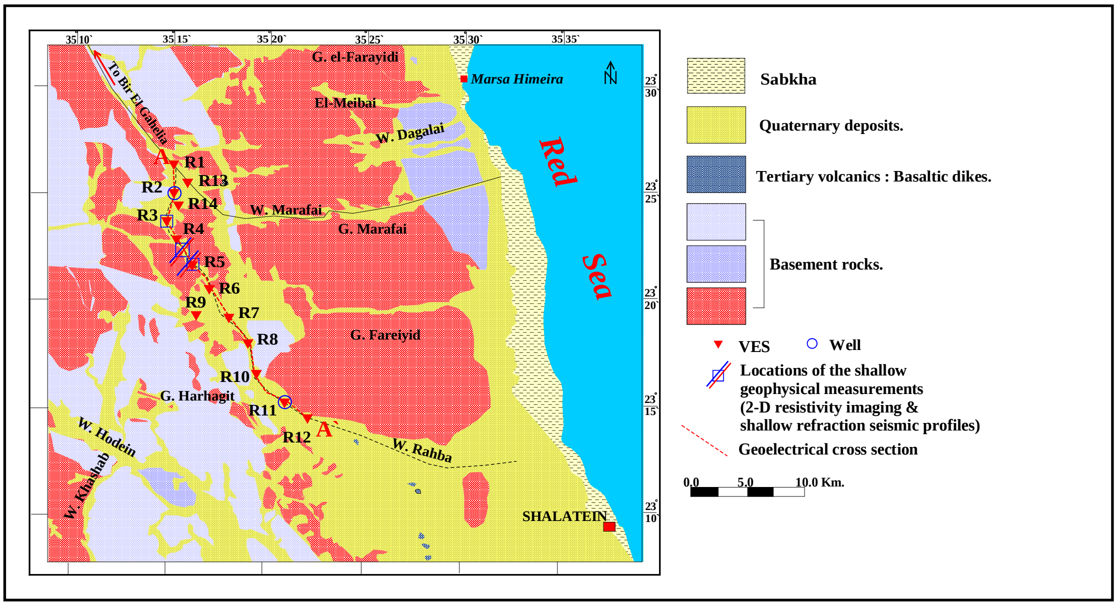

Fig. (3): Location map of the Wells, VES stations, 2-D electrical resistivity imaging and the shallow refraction seismic profiles along Wadi El Rahba.

1.a- Vertical Electrical Sounding:

The geoelectrical resistivity survey has been accomplished by 14 Vertical Electrical Sounding (VES) stations measured along the main channel of Wadi El Rahba. Two test wells were drilled close to the sounding stations 2 and 11, and the data was used to verify the sounding interpretation. The Schlumberger 4-electrode configuration was applied. The current electrode separation (AB) ranges from 200 m to 600 m. This electrode separation proved to be sufficient to reach the required depth that fulfils the aim of the study in view of the geologic and hydrogeologic information. The measured apparent resistivity is plotted versus the corresponding values AB/2 on bilogarthmic paper in the form of VES curves (Fig 4). Use was made of the direct current resistivity meters (Terrameter SAS 300C) to carry out the geoelectrical measurements. The instrument directly measure the resistance (R) at each electrode separation with high accuracy.

Interpretation of the VES curves was carried out using computer program RESIX-PLUS, ver.2.39 (Interpex, 1996). It is an interactive, graphically oriented, forward and inverse modeling program for interpreting the resistivity curves in terms of a layered earth model. The data of wells drilled by the WEP project, (2004), (world food project), development of Bedouin communities, Red Sea., within the area were used as a model for the interpretation of the curves VES curves.

1.b- 2-D Geoelectrical Imaging :

The Wenner electrode array was used in this study. The measurements start at the first traverse with unit electrode separation "*a*" and was increased at each traverse by one unit, i.e. *2a, 3a, 4a ...,na*; where n is a multiplier (Fig.5). The length of the profile, depth of penetration and the required resolution determine the applied unit electrode separation, while the width of the wadi channel determines the profile total length. Three imaging profiles were conducted in the area.

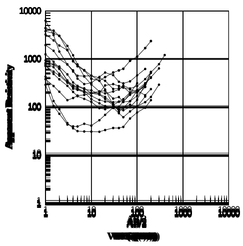

Fig. (4): The field curves of the vertical electrical soundings in Wadi El-Rahba.

For the interpretation of the imaging data, use was made of the computer program RES2DINV, ver 3.4 written by Loke (1998). It is a Windows-based computer program that automatically determines a two-dimensional (2-D) subsurface resistivity model for data obtained from the electrical imaging surveys (Griffiths and Barker 1993). A forward modeling subroutine is used to calculate the apparent resistivity values, and a non-linear least-squares optimization technique is used for the inversion routine (deGroot-Hedlin and Constable, 1990 and Loke and Barker 1996a). This program can be used for surveys using the Wenner, pole-pole, dipole-dipole, pole-dipole, Schlumberger and rectangular arrays.

1.c- Shallow Refraction Seismic :

The major strength of the seismic refraction method is its ability to resolve lateral variations in the depth to the top of a refractor and the seismic velocity within it (Palmer, 1991). This strength is particularly important in the exploration of shallow targets such as shallow structures and shallow aquifers.

Two seismic profiles were conducted at the sites of the 2-D profiles. Use was made to the Seismic Refraction Interpretation Software "Seis REFA" (ver. 1.30 –1989).

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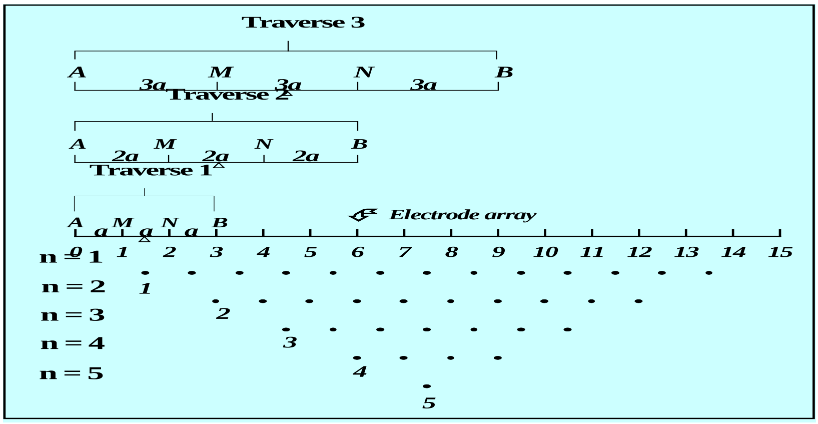

Fig. (5): The measurement sequence for building up the imaging section.

2 - Land Topographic Survey:

Land topographic survey was carried out by using geographical position system (GPS) in order to determine the accurate locations of the geophysical measurement points and their elevations relative to sea level.

DISCUSSION OF THE RESULTS

a- The Vertical Electrical Resistivity Sounding:

The qualitative and quantitative interpretation of the 14 VES curves was carried out making use of the drill hole data available for the VES stations R2 and R11. The interpretation revealed that the geoelectrical succession in the area consists of five layers as shown in figure (6.a, 6.b) and table 1. The interpretation model was followed up for all VES stations where it was possible to construct the geoelectrical cross section shown in figure (7).

Table (1): Resistivity ranges, thickness variations and corresponding lithology of the detected geoelectrical layers

Layer No.	Resistivity (Ohm-m)	Thickness (m)	Corresponding lithology
1	200-1100	15-38	dry wadi deposits (boulders and gravels)
2	10-300	4 – 20	dry wadi deposits (fine sediments)
3	30-60	2.5-4	wadi deposits (water bearing)
4	85 - 260	3 - 5	Fractured basement (water bearing)
5	>500	-----------	Massive basement

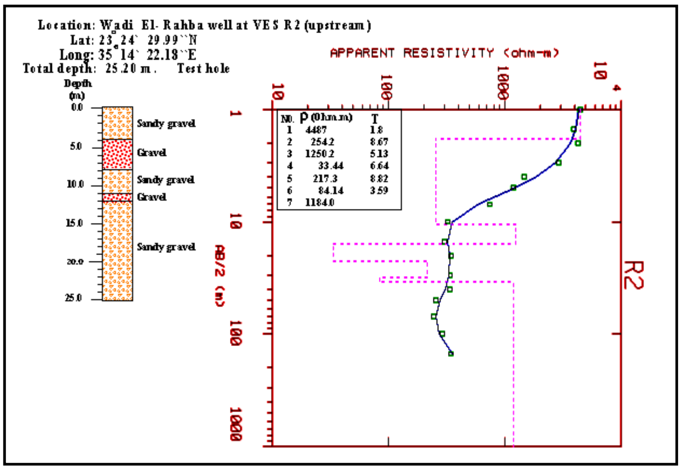

Fig. (6.a) : The geoelectrical results and lithologic data at VES station No. R2.

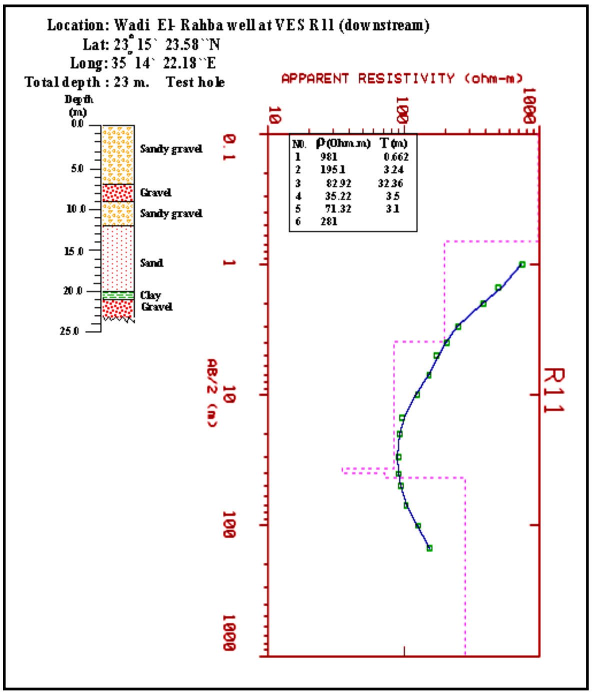

Fig. (6.b) : The geoelectrical results and lithologic data at VES station No. R11.

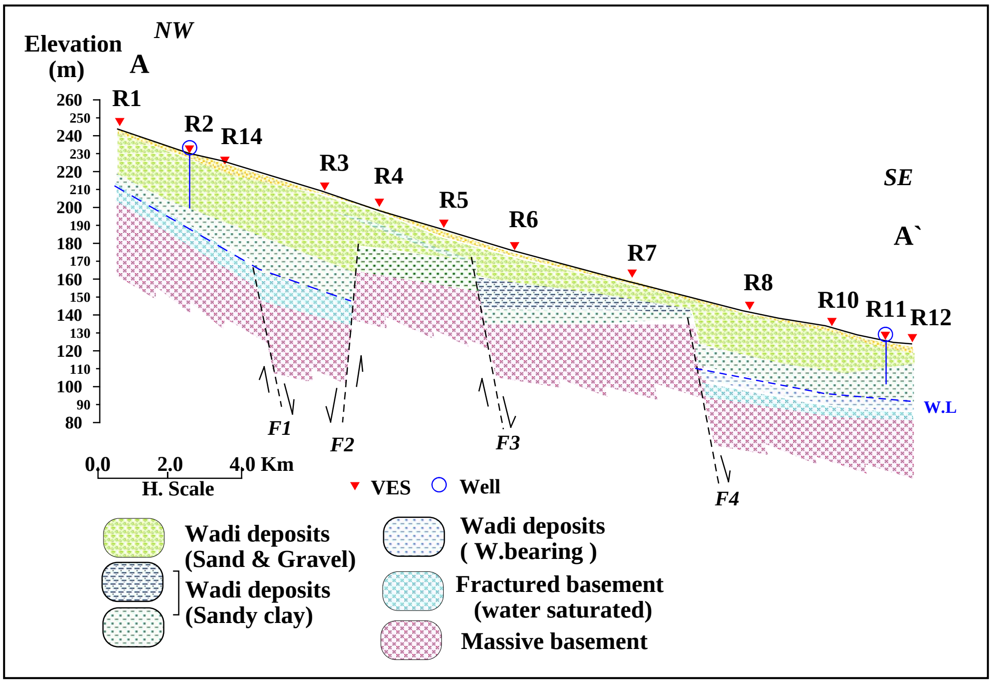

Fig. (7) : Geoelectrical cross section A-A` along Wadi El Rahba.

A generalized description of the succession is given as follows.

- The first geoelectrical layer is formed of dry wadi deposits with high resistivity values ranging from 200 to 1100 Ohm.m. Its thickness ranges from 15 m at VES No.7 to 38 m. recorded at VES No.3. The low resistivity values may be due to the presence of silt or sandy soil, while the higher resistivity values are mainly attributed to the presence of boulders and gravels.
- The second geoelectrical layer is characterized by relatively low resistivity values ranging from 10 Ohm-m at VES No. 3 to 300 Ohm-m at VES No. 7. It is composed of dry wadi deposits, with variable thickness ranging from 4 m at VES No. 7 to 20 m at VES No. 3. The lower resistivity values are attributed to the presence of fine sediments.
- The third geoelectrical layer is characterized by relatively low resistivity values ranging from 30 Ohm-m at VES No. 11 to 60 Ohm-m at VES No. 8. It is composed of water saturated wadi deposits detected at depths ranging from 40 to 60m, with variable thicknesses ranging from 2.5 m at VES No. 8 to 4 m at VES No. 11.
- The fourth geoelectrical has a resistivity ranging from 130 Ohm-m at VES No. 11 to 260 Ohm-m at VES No. 3. Its thickness varies from 3.0m at VES No. 3 to 5.0 m at VES No. 11. This layer represents water-bearing fractured basement. It is not detected at VESes Nos. 4, 5, 6 and 7 due the presence of structures of high basement.
- The fifth geoelectrical unit is composed of massive basement rocks with extremely high resistivity values (more than 500 Ohm-m).

The vertical and horizontal extensions of the above described geoelectrical successions are indicated on the geoelectrical cross section. From this cross section, it is clear that four normal faults affect the succession (F1, F2, F3 and F4). These faults are confirmed by the geologic information available for the study area.

b- The 2-D Geoelectrical Resistivity Imaging:

Three imaging profiles were conducted at three sites, the first is close to VES No.3, in a NW-SE direction, the second lies between VES stations No. 4 and 5, it strikes in a SW-NE, and the third profile lies at VES No. 5.; it trends in a SW-NE direction. The interpreted results can be illustrated as follows:

1- Profile No.1: It lies at the site of VES No. 3 with a total length of 480m. The upper is a plot of the measured apparent resistivity pseudo-section down to a datum level n=12. Examination of this section indicates the domination of different variable resistivity zones (down to a depth of about 75m).The lower image is the true resistivity plot obtained after iterations through the inversion program. Examination of this section indicates the domination of three resistivity zones.

- The upper zone represents wadi deposits with resistivity ranging from 20.0 to 500.0 Ohm.m, extending along the upper part of the profile. The high resistivities correspond to wadi deposits, consisting of sand and rock fragments derived from the surrounding rock mountains and the lower resistivities correspond to wadi deposits consisting of fine sediments.
- The second zone represents water saturated fractured basement with a resistivity value of about 260 Ohm.m and thickness of about 10 m. This zone, as indicated on the profile, is detected at a depth of about 55m at the central part of the profile.
- The last zone represents massive basement rocks with a resistivity more than 500 Ohm.m.

2- Profile No.2: It lies at the site between VES stations 4 and 5, with a total length of 210m (Fig. 9). The section indicates the domination of wadi deposits having a resistivity range of 40.0 Ohm.m to 300.0 Ohm.m The depth to basement was detected at about 32m depth. It can be concluded that this location acts as a barrier due to uplift basement which prevents the hydraulic continuity and the water flow through wadi channel.

3- Profile No.3: It lies at the site of VES station No. 5, with a length of 330m (Fig. 10). It is clear along this profile that there are two contradicted resistivity ranges (high and low) detected at almost the same depth of about 45m. This is interpreted as due to a normal fault that brought the basement rocks (high resistivity range) in the upthrown side, against the fine sediments (low resistivity range) in the downthrown side.

In view of the above mentioned results, it can be concluded that the geoelectrical resistivity imaging is a simple and powerful technique. It produces electrical images which are geologically significant regarding the detectability and high resolution of complex, minor and major structures.

c- The Shallow Refraction Seismic:

The shallow refraction seismic measurements were conducted along two profiles; the first lies between VES stations 4 and 5, running in the SW-NE direction. It consists of two successive spreads with each spread 112.5 m in length parallel to the imaging profile. The second lies at VES station No. 5; it was conducted along a profile running in the SW-NE direction, parallel to the imaging profile. It consists of three successive spreads with each spread 110 m in length.

The interpretation of the shallow refraction seismic data of the two cross sections led to the identification of three main layers. The velocities obtained for the identified layers were coupled with the borehole data, geoelectrical sounding and 2-D resistivity imaging in order that they may explain the subsurface geological setting at the investigated locations.

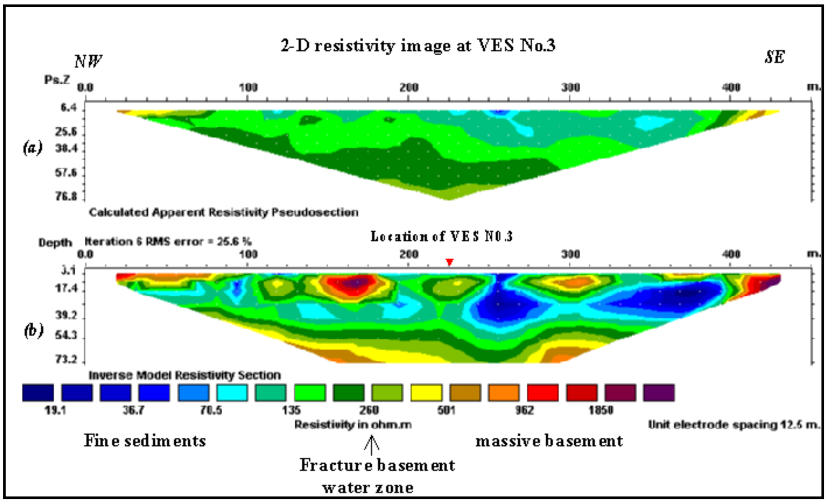

Fig. (8): Resistivity image crossing to Wadi El Rahba at VES No.3.

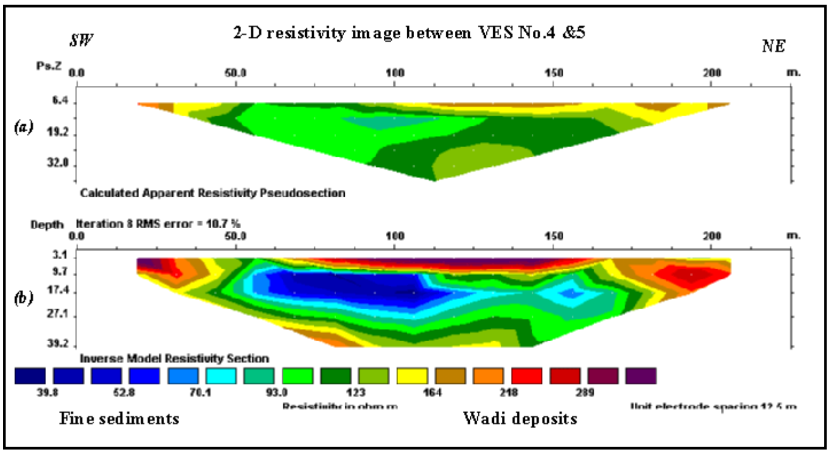

Fig. (9): Resistivity image crossing to Wadi El Rahba between VES No.4 & 5.

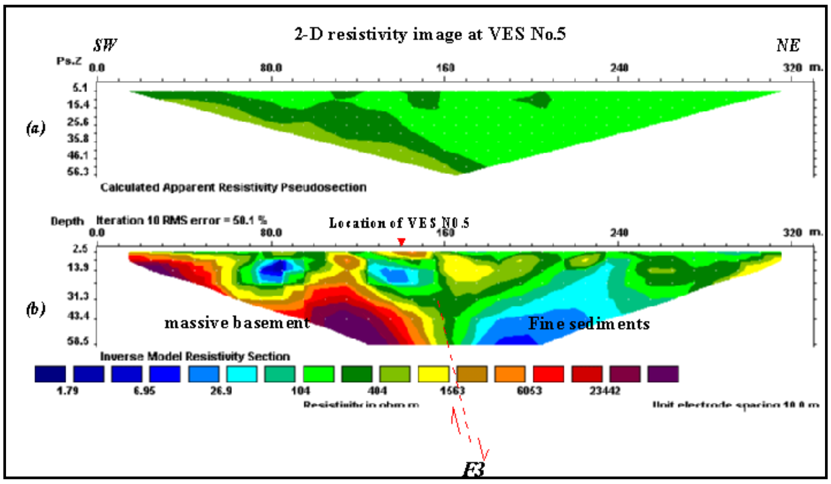

Fig. (10): Resistivity image crossing to Wadi El Rahba at VES No.5.
(a) : apparent resistivity pseudo-section.
(b) : True resistivity plot.

- **Profile AA':** This profile runs across the wadi between VES stations 4 and 5, with a length 225 m. The investigated depth along this profile is 15-20 m. Three geoseismic zones could be identified along this profile (Fig.11). The uppermost one has a thickness of 2-5m with a velocity of 0.4km/sec, and represents wadi deposits. The second zone downward is about 10m thick and velocity of 1.0 km/sec. It represents silt, wadi fill deposits. The difference in velocity between the upper zone and this zone could be attributed to the upper zone being of more fine deposits than the second one. As a matter of fact this is evident from the test hole data. The last geoseismic zone downward has a velocity of 2.3 to 3.3 km/sec, which can be attributed to fine wet sediments. The difference in depth of the detection of this zone between the northeastern and southwestern part of the profile can be attributed to the relief of the underling basement.

- **Profile BB':** The length of this profile reaches 330 m crossing the wadi at VES station No.5. The investigated depth in that profile reaches about 30 m. The succession can be identified as three zones (Fig. 12)., the first is the surface zone with a thickness of 3- 5 m and velocity 0.35 km/sec. The second zone has a velocity range of 1.2 to 2.0 km/sec and thickness of 5-20 m, which corresponds to Quaternary wadi deposits. The third zone is represented by indurated boulders and basement fragments with fine to medium sediments which are detected at shallow depth with a speed of 4.4 km/sec at SW side of the channel, while it is detected at more depth in the NE side. This condition is attributed to the structural effects such as normal faulting.

GROUNDWATER OCCURRENCE

The geoelectrical survey revealed that the groundwater exists in the investigated area at the upstream and the downstream parts of wadi El Rahba. In the middle part of the wadi a basement uplift forms a barrier against the hydraulic continuity through the wadi channel. The upstream part of the aquifer is formed of fractured basement with a thickness of 3-5m and resistivity of 85-260 Ohm.m (VES stations 1, 2, 3, 13 and 14). The depth to water is detected at 35 to 55m. Groundwater in the downstream part of the wadi exists in two layers, the upper layer consists of wadi deposits with a thickness of 2.5-4m (VES stations 8, 9, 10, 11 and 12) and resistivity of 30-60 Ohm.m. The lower water bearing layer is formed of fractured basement with a resistivity of 80-250 Ohm.m and thickness of 3 to 5m. The depth to water at the downstream part of the wadi ranges from 40 to 60m.

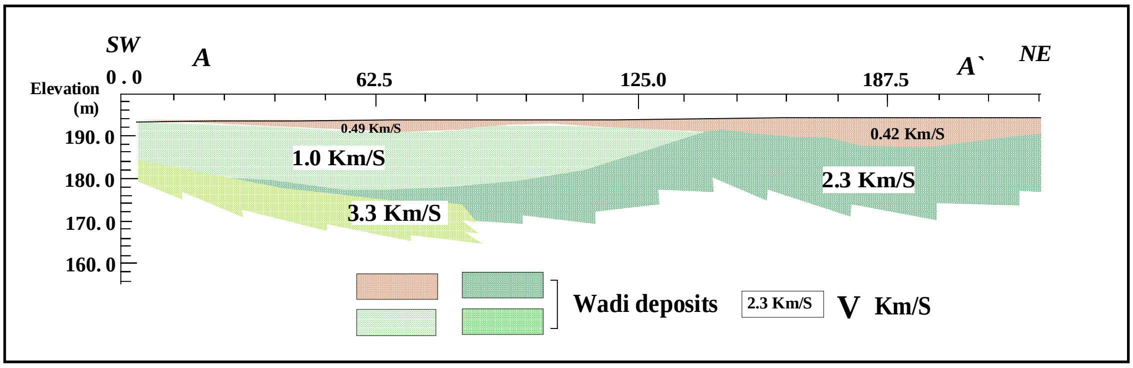

Fig. (11): Geoseismic cross section (AA`) between VES stations No. 4 and 5.

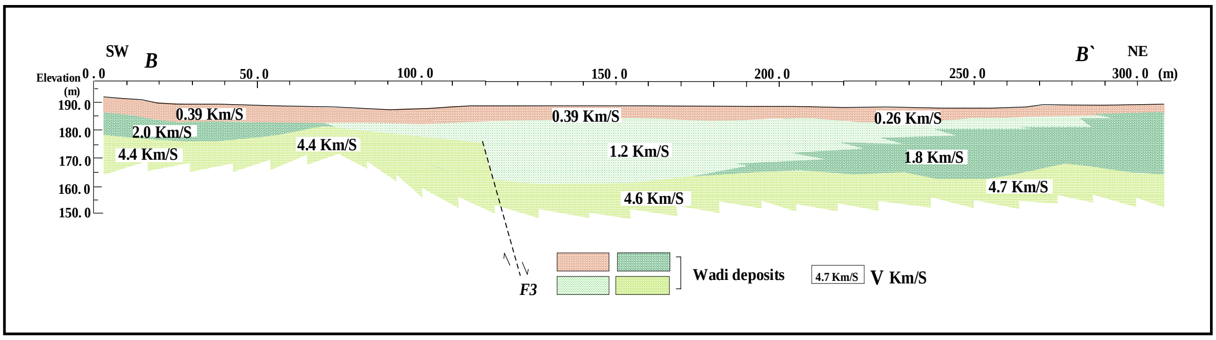

Fig. (12): Geoseismic cross section (BB`) at VES station No. 5.

SUMMARY AND CONCLUSIONS

The present study area lies in the southern part of the Eastern Desert. The geophysical measurements included 14 geoelectrical resistivity soundings, three Electric Resistivity Imaging Profiles (Tomography) and two Refraction Shallow Seismic surveys along Wadi El-Rahba. The available geological and hydrogeological data are used in the interpretation of the geophysical measurements.

In the geoelectrical resistivity survey, the qualitative and quantitative interpretations revealed the existence of five main geoelectrical layers. The first and the second layers are: dry wadi deposits, the third layer is water saturated wadi deposits represented only at the down portion of the wadi, the fourth layer is water saturated fractured basement rocks that present at the upper and lower parts of the wadi, and the last layer is crystalline basement representing the base of the aquifer. The succession was found to be dry at the middle part of the wadi channel due to a horst structure. This was also confirmed by the test hole 1 and 2 at the sites of VES stations R2 and R11, respectively which were drilled down to 25m only (did not reach the saturated zone).

The results indicate that the relatively suitable sites for water well drilling are those at the sites of VES stations 1,2,3,13 and 14 upstream of the wadi where groundwater is present in fractured basement. Similarly, the sites of VES stations 8, 9, 10, 11 and 12, downstream of the wadi are suitable for the same purpose, where water is present in wadi deposits and fractured basement. The aquifer thickness at both locations is relatively reasonable.

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