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CONTRIBUTION OF GROUND MAGNETIC AND RESISTIVITY METHODS IN GROUNDWATER ASSESSMENT IN WADI BANY OMAIR, HOLY MAKKAH AREA, SAUDI ARABIA

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إسهامات طرق المغناطيسية الأرضية والمقاومة النوعية فى تقييم المياه الجوفية فى وادى بنى عمير- مكة المكرمة - السعودية

الخلاصـة: يقع وادى بنى عمير ضمن مربع منطقة مكة المكرمة بين خطى طول 39º 54' 39.4" & 40º 03' 41.0" شرق ، وخطى عرض 21º 39' 31.0" N & 21º 41' 01.7" شمال. يكتسب هذا الوادى أهميته من حيث موقعه قرب مدينة مكة المكرمة بحوالى ٢٠ كيلومتر. وهو أحد أهم روافدِ وادى فاطمة ذى الأهمية حيث يساعد في تغذية المناطق الغربية بالمملكةِ العربية السعودية بالمياه الجوفيّةِ.، وهذا الوادى هو جزء ضمن القطاع ِ الأوسط الغربيِ للدرعِ العربيِ، الذي يتكون من الصخورِ الناريةِ ِ مِنْ عصر ما قبل الكمبرى، صخور بركانية مِنْ عصور الميوسين والباليوسين بالإضافة إلى الرواسبِ الحديثة من العصر الرباعيِ.

إنّ الهدفَ الرئيسيَ من هذه الدراسةِ يتمثل فى تقييم إمكانيات المياه الجوفيّةَ بالمنطقة منَ خلال تَحديد أكثر المواقعِ مناسبة لحفر الآبارِ المُنْتِجةِ في الوادى. ولتحقيق هذا الهدف تم إستخدام طريقتى المغناطيسية الأرضية والمقاومة الكهربية النوعية. لذا فقد تم تغطية الوادى بحوالى ٤١ خط مغناطيسى عمودى على الإتجاه الرئيسى للوادى وكذلك فقد تم تنفيذ عدد ١٠٦ جسة كهربية رأسية بإستخدام توزيع شلمبرجير بحيث تغطى حوالى ٢٠ كيلومتر هى طول منطقة الدراسة من الوادى. لقد أُخضعتْ بيانات الشدة المغناطيسيةِ الكليّةِ إلى الترشيح لفصل المركبتين الإقليميةِ والمتبقيةِ على عمقين تم تحديدهما مِنْ المنحنى الطيفِى لكُلّ خط مغناطيسى على حدة. وتم تحليل بياناتِ الجس الكهربى الرأسى بإستخدام نوعين من برامج التحليل الحديثة وهما برنامج زهدى (١٩٨٩) لعمل نماذجِ متعددةِ الطبقات وبرنامجَ IPI2WIN (٢٠٠١) لعمل النموذج الطبقى لكل جسة كهربية.

لقد تبين من تكامل نتائج الدراسة الجيوفيزيائيةُ المشتركةُ للطرق المغناطيسية والكهربية أن العمقُ الأقصى لصخور القاعدة بالوادى يبلغ حوالى ٦٨ متراً، وأن أقل عمق لتلك الصخور تم تسجيله بالوادى يبلغ ٨ أمتار، وعليه فقد وصل متوسط عمق صخور القاعدة بالوادى حوالى٣٥ متراً. وقد أتضح أن متوسط سُمك الطبقة المُشبَعةِ بالماءَ بالوادى يَصِلُ إلى ١٤ متراً وأن العمق إلى سطح تلك الطبقة المشبعة يبلغ متوسطه حوالى ٣٠ متراً بالوادى. وقد نَجحتْ الدراسةُ فى إختيار عدد٢٥ موقعَ وَاعِدَ تُمثّلُ المواقعَ الأكثر ملائمة لحفر عدد من الآبارِ الإستطلاعيةِ في منطقةِ الدراسة.

ABSTRACT: *Wadi Bany Omair is located within Makkah quadrangle, between Longitudes 39º 54' 39.4" E & 40º 03' 41" E, and Latitudes 21º 39' 31" N & 21º 41' 01.7" N. This wadi acquires its importance from its location near the Holy Makkah town by about 20 km. It is one of the most important tributaries of wadi Fatima, which contributes in feeding the western parts of Saudi Arabia with groundwater. The study area lies within the western central section of the Arabian Shield which, consists of plutonic igneous rocks of Precambrian age, volcanic rocks from Miocene and Paleocene age as well as Quaternary sediments.*

The main objective of this study is to asses the groundwater potentiality through locating the most suitable sites for drilling productive wells in the wadi. The ground magnetic and DC resistivity methods were used to achieve this aim. The wadi was covered by about 41 ground magnetic profiles perpendicular wadi direction and about 106 vertical electrical soundings (VES) with Schlumberger configuration in a total distance about 20 km along the wadi. The total magnetic intensity data were subjected to regional-residual separation at two depths, determined from power spectrum curve for each profile. The VES data analysis was performed using two geoelectric software; ATO program of Zohdy (1989) to construct the multi-layer models and IPI2Win program (2001) for layering models.

The combined geophysical study revealed that the maximum depth to the basement is 68 m, and the minimum is 8m, with an average value of 35m. Also, the average thickness of the water-saturated zone reaches 14 m and the depth to the water table is 30m. The study succeeded to postulate 25 promising sites, which represent the most appropriate locations for exploratory wells in the region.

INTRODUCTION

The population increases in the Kingdom of Saudi Arabia (KSA) and in particular in the Holly city of Makkah, in addition to the increase in the development, social and consuming lifestyle has depleted the natural and environmental resources extensively, and most important is the water. The continuous increase on water consumption especially in Makkah is a reflection of the condition in the kingdom. Figure 1 shows, the location of Holly Makkah city in the KSA.

The main objective of this study is to explore the groundwater potentiality and to establish its hydrogeological condition in order to locate the positions of production wells in this wadi, managing its groundwater and preserving its reserve during critical and dry seasons. To achieve these goals, the authors used the ground magnetic and electric methods as effective geophysical tools in such studies.

Geophysical techniques have proved to be efficient tools in groundwater exploration and the steep technological growth of the last 15 years in geophysics, due mainly to advances in microprocessors and associated numerical modeling solutions that considerably have affected this field of geophysics. Not only has geophysics been used in the direct detection of the presence of water but also in the estimation of aquifer size and properties, groundwater quality and movement, mapping saline water intrusions and buried valleys even in areas of complex geology (UNESCO, 1998). Besides, geophysics can be used to screen potential drilling locations, decreasing the risk of drilling in unproductive areas (Tsiboah, 2002).

Location of the Area

Wadi Bany Omair lies about 30 Km from Makkah near Zima town which is on the Al-Sail-Makkah road and extends for about 20 Km in length. It is located within Makkah quadrangle, between Longitudes 40º 03' 41" & 39º 54' 39.4" E, and Latitudes 21º 41' 01.7" & 21º 39' 31" N (Fig. 1). The wadi trends from the escarpment of the mountain region with different degrees of gradients, which generally decrease away from the elevated regions. The general physiography of the wadi is that of high elevation and steep sides ranging between 35-40 degrees, with conical and semi-conical hills. Alluvial terraces and alluvial fans are also found. It slopes gently westwards. The highest point recorded in the area of study is about 520 m whereas the lowest one is about 440 m. Assessment of the morphology of the wadi is important in this study, as it identifies the recharge area for the groundwater aquifers. High gradients contribute to larger degree of run-off's, while gentle slops allow more for percolation, thus more recharge. The general geological and topographical features of the wadi are shown in Figure 2.

Geology of the Area

The geological structures contribute significantly to the development of the drainage patterns specifically in the upper parts of the wadi. The shelf lies to the east, south and a large segment of the northern areas. The intrusive and extrusive rocks as well as metamorphic rocks are confined to the Arabian Shield which occupies the western part of the kingdom and represents one third of the area. The wadi, that represents the object of this study lies within the western middle section of the Shield area, which consists of layered and plutonic igneous rocks of Precambrian age. Also volcanic rocks from the Miocene and Paleocene age appear on the fringes of the wadi. Surface alluvials of Quaternary period also prevail (Fig. 3).

The Precambrian granitic and basaltic rocks are common in this wadi as well as the Ja'arana Group which consists of tonalite and granodiorite that are characterized by a low distortion and metamorphism. Jammom Group appears in the central parts of the wadi and consists of a mixture of amphibolite and quarts–feldspar schist. Also, appears in this group the Para-gneiss and layers of marble. The age of these two groups is not well defined. Dykes exist in many parts having E-NE bearings. Also there are many fault systems distributed in many directions in the area. The wadi sediments of sands and gravels with different grain sizes are congregating in the course of the wadi. As in other sites they provide good water reservoirs and the thickness is 50 m in certain parts.

GEOPHYSICAL SURVEY

The geophysical study has been carried out using the magnetic and electrical resistivity methods. The magnetic method is aimed to determinate the depth to the basement rocks in the wadi and the general nature of their types and structural features, joints and faults, which are controlling the rocks. The resistivity method is used to determine the alluvial geology and the possible presence of water as well as the thickness of the water bearing horizon within.

Magnetic Method

The magnetic method has expanded from its initial use solely as a tool for finding iron ore to a common tool used in exploration for minerals, hydrocarbons, groundwater, and geothermal resources (Nabighian, et. al., 2005). The method is also widely used in other applications such as studies of water-resource assessment (Smith and Pratt, 2003; Blakely et al., 2000) and determining most suitable location for water accumulation based on the estimation of depth to the basement and other related geological structures. It mainly uses to locate the thickness of the surface alluvial sediments and their basins. Despite the fact that sediments of this type have little magnetic effect due to the absence of magnetic minerals, the relatively high magnetic susceptibility acquired by the basement rocks are targeted in this study. Their detection and depth estimation indirectly provides estimates of the sediments and the possible volume of water storage which is invaluable to this study.

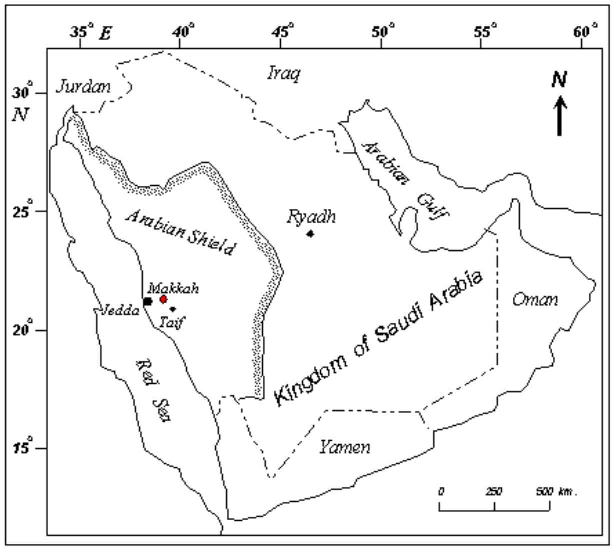


Fig. 1: Location map of Saudi Arabia (KSA) showing the study area.

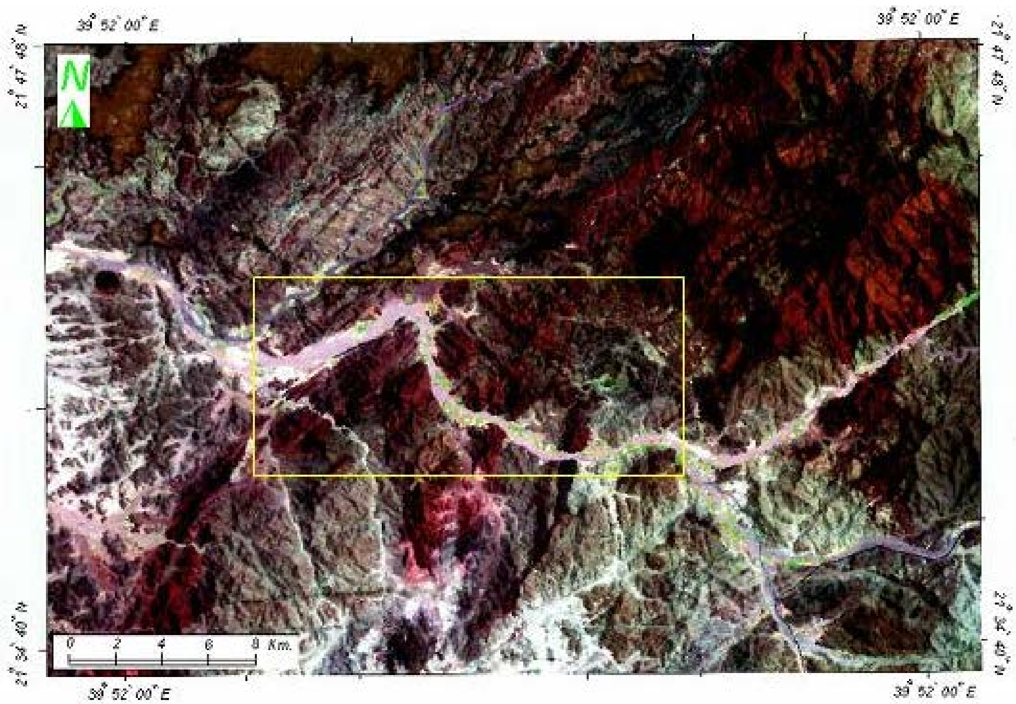


Fig. 2: A satellite image showing the general geological and topographical features of wadi Bany Omair.

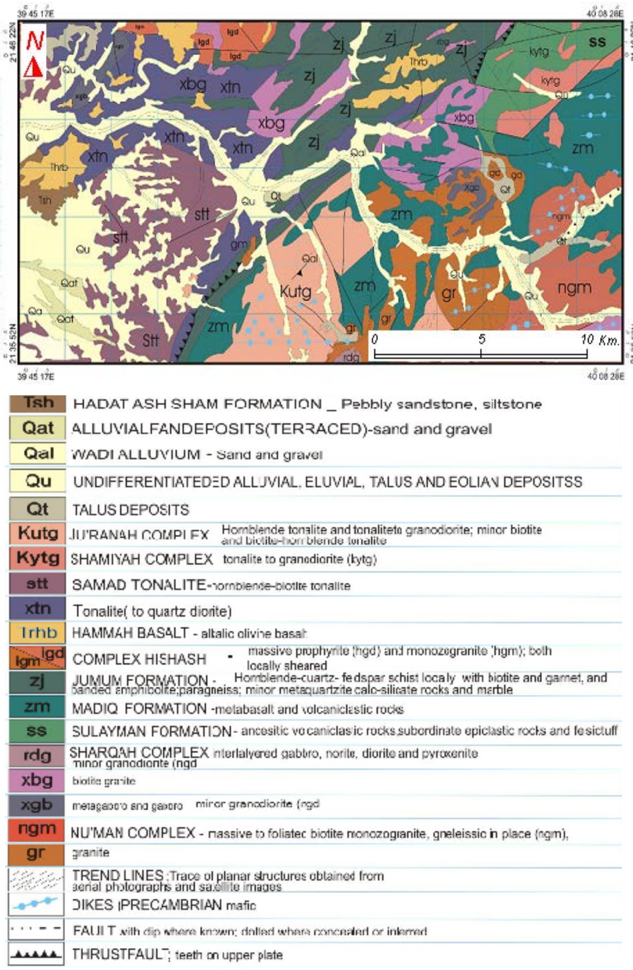


Fig. 3: Geologic map of wadi Bany Omair area (after Saudi Geological Survey, 1986).

The total Intensity values were measured along profiles running across the course of the wadi with successive spacing between profiles ranging from 200 to 500 m depending on the prevailing conditions of the wadi (Fig. 4). The lengths of these lines range from 300-2400 m, depending on the changing width of the wadi. The spacing between successive stations was 20 m in N-S or E-W directions. The profiles start at the upper parts of the wadi to the east and end at the lower borders of the wadi, to the west, covering 20 Km of its length. A tie- line was chosen along the strike of the wadi which runs across the transverse lines. The measurements were taken using Geometrics magnetometer Model G-856 and the position and orientation of the profiles were fixed using GPS-UTM system.

Resistivity Method

The electrical resistivity method is an adequate geophysical tool for groundwater exploration as it can determine the aquifer thickness and the depth to the bedrock. It is also used to determine the quality of groundwater i.e., whether the water is saline, brackish, fresh or contaminated (Zohdy, 1974; Stollar and Roux, 1975; Rogers and Kean, 1980; Urish, 1983).

The direct current (DC), also called "galvanic", electric resistivity method measures the resistance to flow of electricity in subsurface material. DC methods involve the placement of current electrodes on the surface for current injection into the ground. The current stimulates a potential response between two other electrodes (potential electrodes) that are measured by a voltmeter. Resistivity (measured in ohm-m) can be calculated from the geometry and spacing of the electrodes, the current injected, and the voltage response.

VES is designed to provide vertical profiles of resistivity versus depth. Although most electrode configurations can be used for VES, the Schlumberger arrangement offers an advantage where only two electrodes can be moved at a time. The mid-point of the array is kept fixed while the current and potential electrodes are maintained at the same relative spacing and the whole spread is progressively expanded about the center. Consequently, readings are taken as the current reaches progressively greater depths. The total of 106 soundings was carried out in this wadi which is 20 Km in length. The soundings are distributed so that they are about 500 m apart. Other soundings were carried out at 250 m along the same line (Fig. 5). The equipment used in the present study is a D C resistivitymeter model CAMPUS-Ω.

DATA ANALYSIS, PROCESSING AND INTERPRETATION

Magnetic Data

The visible changes in the magnetic intensity, on the traverses, are an indication to variations in the depth of the bed rock, mineralogical changes and their structure along the profile. The total intensity magnetic map of wadi Bany-Omair (Fig. 6) indicates that the basement rocks covering the wadi floor are diverse acidic and basic types. It also reveals the presence of systems of faulting which cause changes in the basement level. The wadi, based on this map, can be subdivided into 3 zones: The first zone is represented in certain parts of the east and central section of the study area has magnetic intensity values ranging from 40400 to 42800 gammas. The high magnetic values of this zone are correlated geologically with highly magnetic ultrabasic rocks. The second zone covers most of the eastern section and parts of the central and western areas have magnetic intensity around the average for the readings and range between 40240 and 40400 gammas.

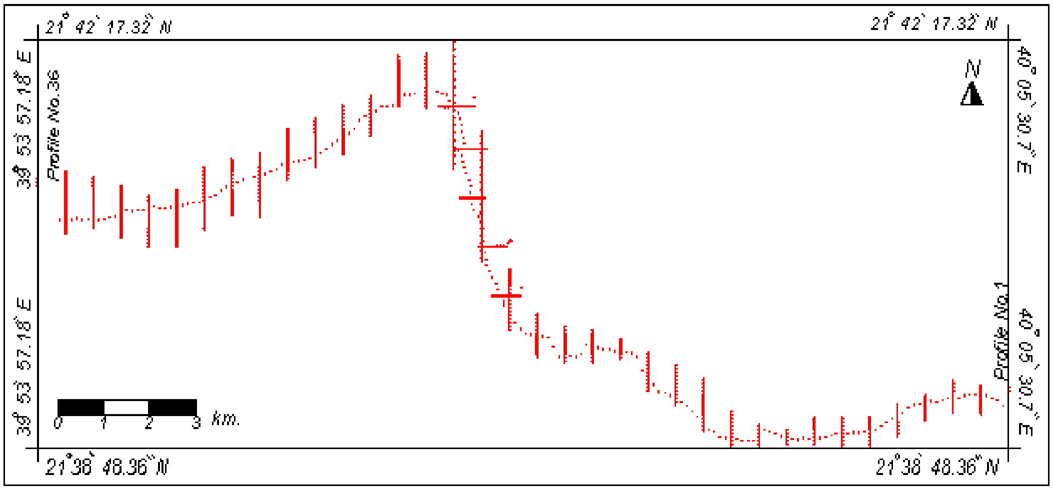


Fig. 4: Layout map showing the distribution of magnetic survey lines in wadi Bany Omair.

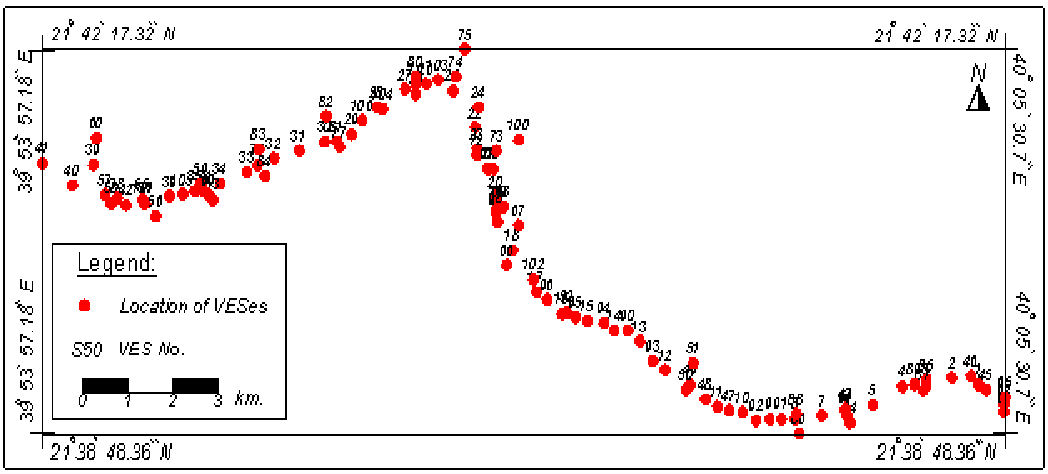


Fig. 5: Layout map showing the distribution of VES's in wadi Bany Omair.

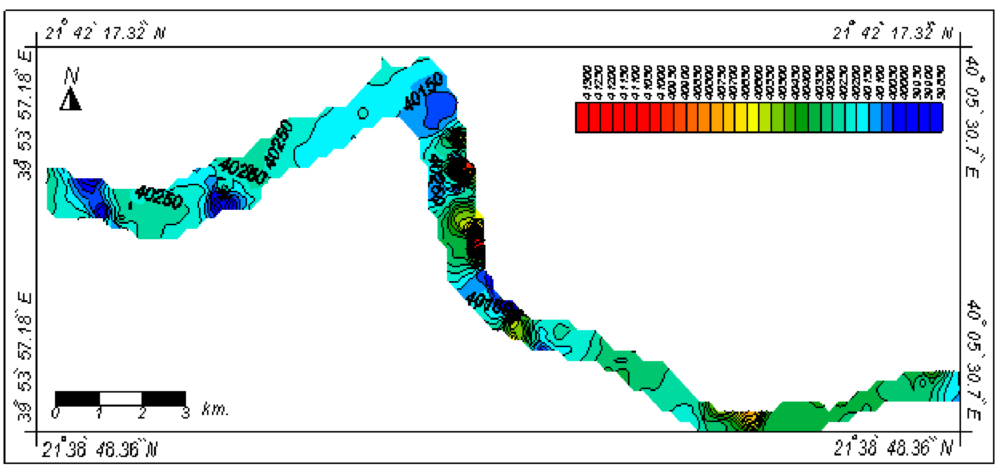


Fig. 6: Total intensity magnetic map of wadi Bany Omair.

This zone may associate with acidic rocks lying at shallow depth. The third zone covers approximately half of the study area at the western and central parts has low intensity values agreeing with acidic basement rocks at relatively larger depth.

In geophysical investigations of the subsurface structures; the most important parameter to be estimated is the depth to the anomalous structure (Sharma, 1976). The first step in the isolation of the magnetic anomalies into deep-seated (regional) and near-surface (residual) components were conducted through the analysis of the energy spectrum of the magnetic data. The presentation of the spectral analysis method depends on plotting the energy spectrum against frequency on a logarithmic scale. The plot shows straight-line segments which decrease in slope with increasing frequency. The slopes of the segments yield estimates of average depths to magnetic sources, therefore the depth calculates as Slope/4π* Scale. Calculation of the power spectrum for each profile was carried out using Filon Fourier Transformation (FFT) in which magnetic readings in space domain is transformed into frequency domain (Sadek 1987). The application of the power spectrum analysis on the magnetic data of the present area revealed presence of two main average levels (interfaces) at 41 and 129 m for the residual and regional components respectively below the measuring level (Fig. 7). Accordingly, the magnetic method was capable in locating structural zones controlling the distribution and movements of the groundwater and the thickness of the sedimentary cover which constitutes a major element in the hydrogeological studies.

The total magnetic intensity data of the measured traverses were subjected to the process of regional-residual separation at the two depths determined from the constructed power spectrum curve. The two components for each profile as well as the total intensity are presented in one graph. This presentation facilitates the interpretation and picking up the significant magnetic anomalies. Figure 8, is a selected example for this presentation.

Table 1; demonstrates the mean depths to the bedrock in the wadi that was calculated from the magnetic anomalies. The table lists the line number, coordinates and the depth of the residual component of all lines. It is evident that maximum depth was at anomaly 30T while lowest values were at anomalies in lines 6, 9 and 37. A mean value of 42 m represents large proportion of the calculated stations in the study area.

In Figure 9, a longitudinal cross section along wadi Bany-Omair is displayed as well as the general topography of the basement as deduced from the magnetic profiles. The figure demonstrates that the wadi floor is influenced by a system of vertical lateral faults and variation in mineralogical composition of the rocks. In general the depth of the basement increases westwards and it is shallower towards the east. Also in the central part there are variations in depth in which certain parts indicate deep basement.

VES Data

The VES field data were treated to reduce the different segments of the sounding curve into a continuous curve, to clean out the noise from the curve and to plot the corrected sounding curve. Therefore, the data analysis was performed using suitable modern two geoelectric software to obtain the equivalent true resistivity models for each sounding. The first is the ATO program of Zohdy (1989), that is used to convert the values of (AB/2) and (ρ_a) into a multi-layer model. It is a fully automated, fast iterative method based on obtaining interpreted depths and true formation resistivities from shifted electrode spacing and adjusted apparent resistivities respectively. The n-layer model can provide additional information about the subsurface variations within any suggested geoelectric layer (Sadek, et al., 1989). Due to the lack of subsurface geological information in this area, the n-layer model can be used to construct an initial model to feed the second 1D modeling program (IPI2Win of Moscow State University, 2001) and helps to obtain the equivalent true resistivity models for each sounding. It is an automated and interactive semi-automated program for vertical electrical sounding interpretation. The justification of the final model is controlled by calculating the root mean square error (RMS error) between the resistivity data resulted from the preliminary curve and the calculated one.

It is worth to mention that, the simplified interpreted curves of the Ato program (Zohdy, 1989), in addition to the regional background on the geology of the area, are used to construct a preliminary model that would fairly fit the observed field curves. This is after a minimum number of non-automatic iterations, which in turns represent the input model of the IPI2Win program. The total soundings were treated and processed in order to construct a geoelectric model for the wadi to guiding us to select the most promising sites which might attain ground water potentialities. Because of the huge number of the executed soundings in the present wadi, the processing results of sounding 102 were chosen for representation (Fig. 10).

Because an interpreter has no a prior information about the exact number of layers which constitute the geoelectric section at a locality, it is customary to assume a number of layers ranging between three and six at the most. If the geoelectric section is made of many more layers than has been assumed, each of the interpreted layers would represent a grouping together of several layers (Kunetz, 1966).

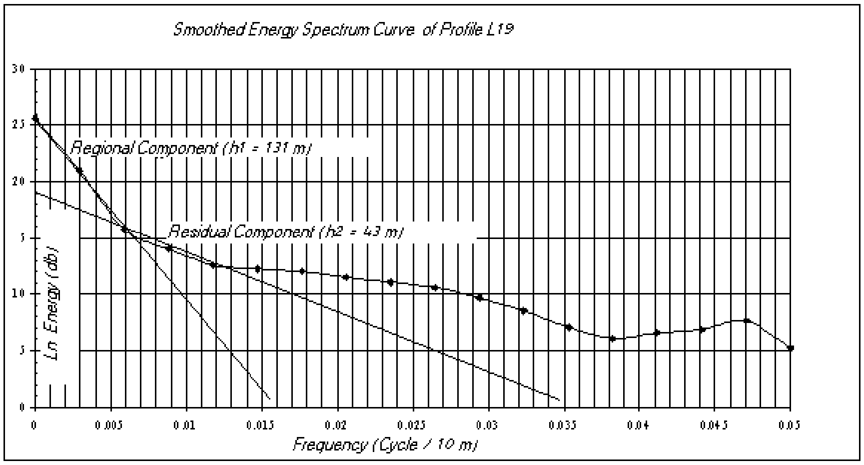


Fig. 7: Power spectrum curve of line No. 19 (selected example).

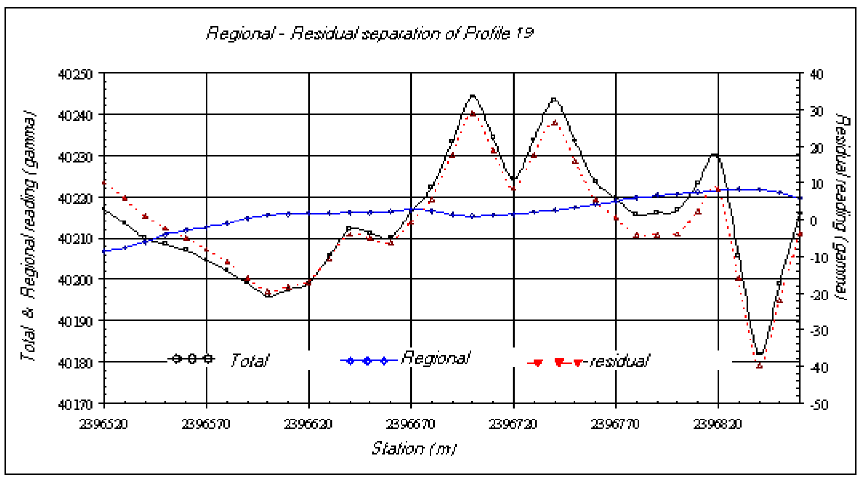


Fig. 8: Regional-residual separation of line 19, wadi Bany Omair (selected example).

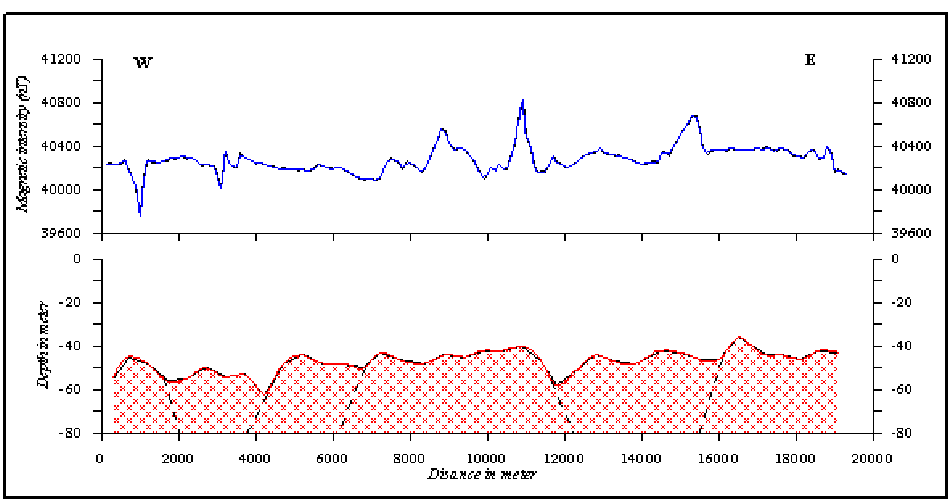
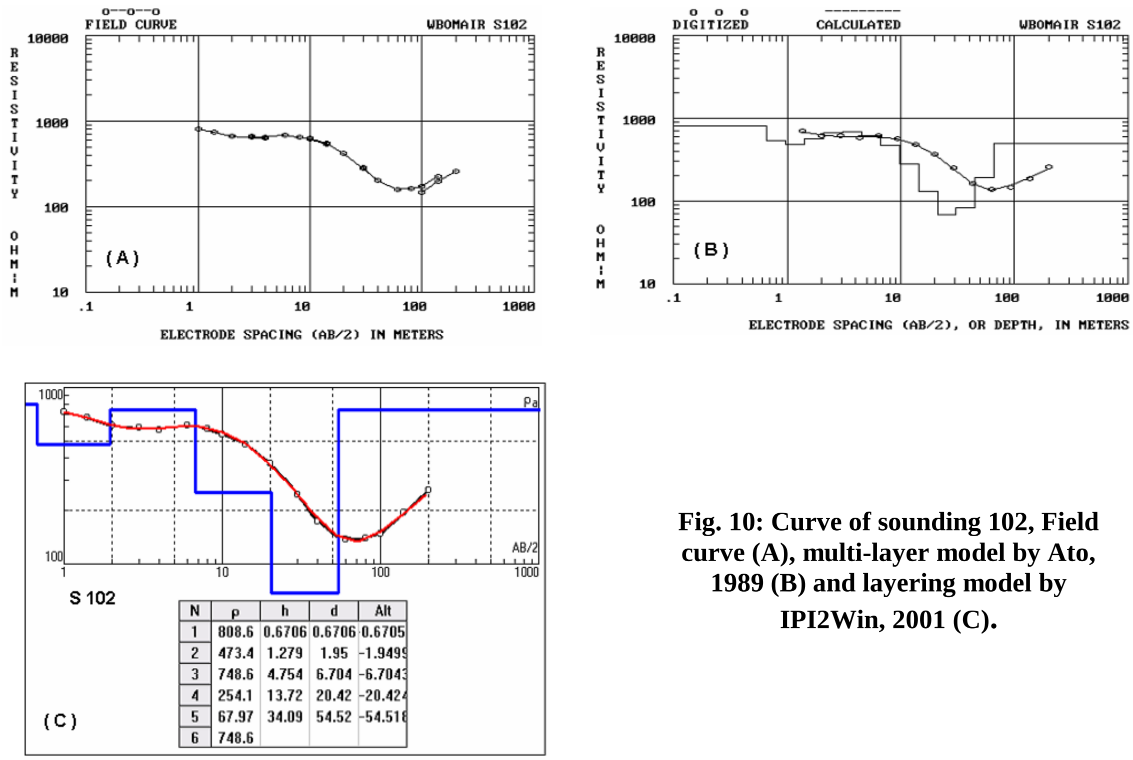


Fig. 9: A longitudinal cross section along Wadi Bany Omair.

Table 1: Calculated mean depth to basement as deduced from ground magnetic survey.

Profile No	Coordinates (UTM)		Average Depth (m)	Coordinates (UTM)		Average Depth (m)
	X	Y		X	Y	
1	610700	2395130	41			
2	610200	2395280	50			
3	609700	2395210	36	609700	2395470	39
4	609200	2395160	53			
5	608700	2395090	25	608700	2394830	24
6	608200	2394630	23	608200	2394890	35
7	607700	2394630	28	607700	2394890	24
8	607200	2394690	25	607200	2394870	29
9	606700	2394680	23			
10	606200	2394720	40			
11	605700	2394670	35	605700	2394950	39
12	605200	2394910	35	605200	2395190	34
13	604700	2395350	23	604700	2395650	40
14	604200	2395590	37	604200	2395890	36
15	603700	2396120	42			
16	603200	2396030	31	603200	2396310	43
17	602700	2396050	36	602700	2356350	26
18	602200	2396530	37	602200	2396170	48
19	601700	2396690	43	601700	2397130	47
20	601200	2398080	47	601200	2399340	46
21	600700	2399560	48	600700	2400680	46
22	600200	2400270	37	600200	2400720	42
23	599700	2400310	52	599700	2400710	50
24	599200	2399770	؟؟؟	599200	2400070	33
25	598700	2399520	47	598700	2399910	43
26	598200	2399310	45	598200	2399690	41
27	597700	2399090	40	597700	2399500	40
28	597200	2398530	50	597200	2399050	39
29	596700	2398550	48	596700	2398990	44
30	596200	2398310	38	596200	2398850	31
31	595700	2398530	42	595700	2398110	34
32	595200	2398410	34	595200	2398030	51
33	594700	2398110	49	594700	2398530	46
34	594200	2398790	44	594200	2398380	41
35	593700	2398810	49	593700	2398250	36
36	593200	2398510	44	593200	2399070	43
37	601650	2397000	23			
38	601310	2397800	31	601590	2397800	26
39	601030	2398600	45			
40	600990	2399400	42			
41	600610	2400100	34			



N	ρ	h	d	Alt
1	808.6	0.6706	0.6706	0.6705
2	473.4	1.279	1.95	-1.9499
3	748.6	4.754	6.704	-6.7043
4	254.1	13.72	20.42	-20.424
5	67.97	34.09	54.52	-54.518
6	748.6			

Fig. 10: Curve of sounding 102, Field curve (A), multi-layer model by Ato, 1989 (B) and layering model by IPI2Win, 2001 (C).

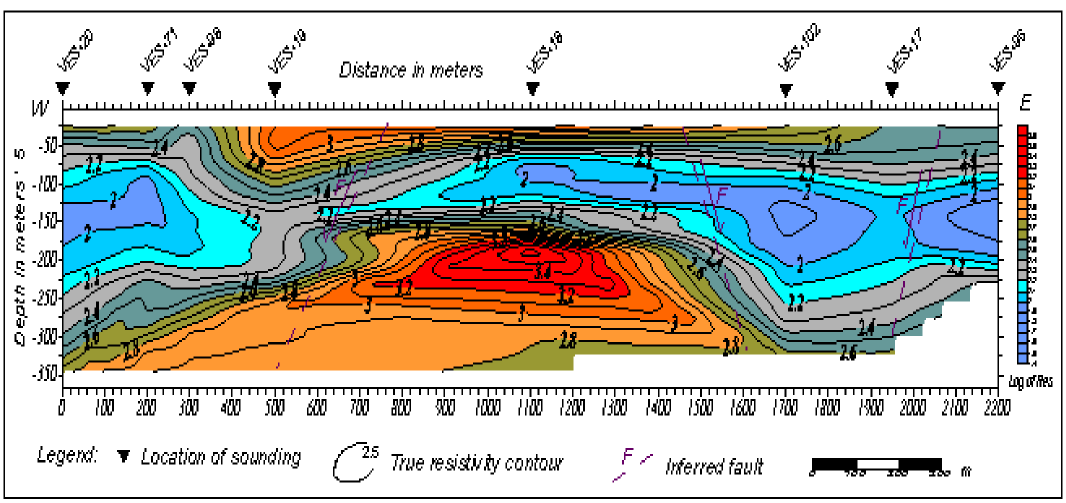


Fig. 11: Subsurface true resistivity contour section, along wadi Bany Omair.

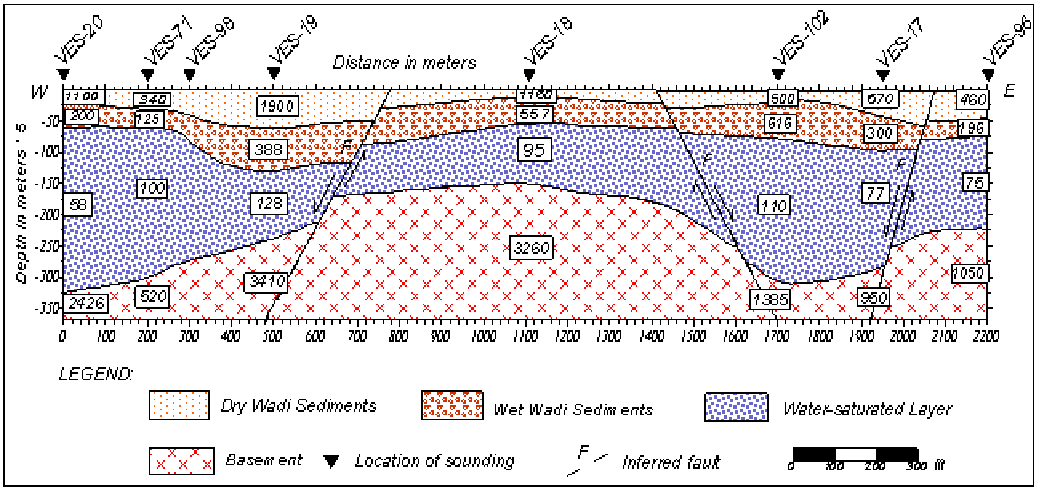


Fig. 12: Geoelectric cross section interpreted from the equivalent contour section (fig. 11).

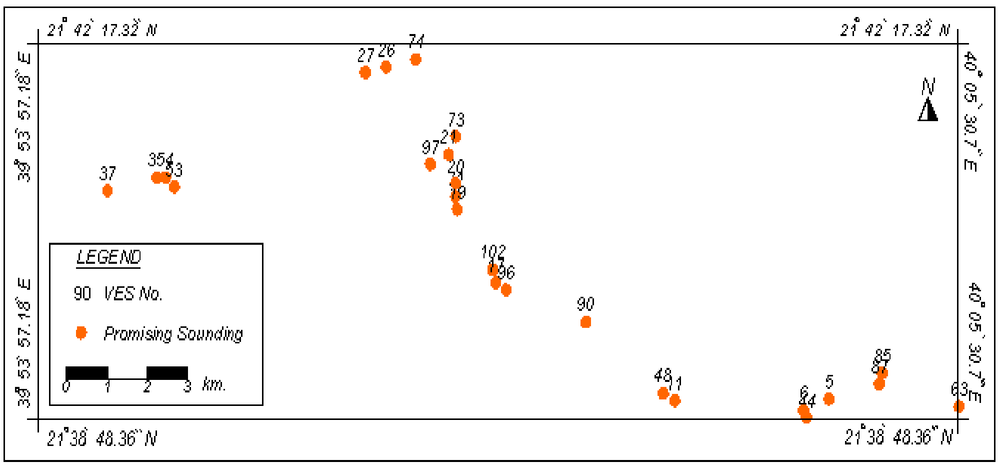


Fig. 13: Locations of promising soundings in wadi Bany Omair.

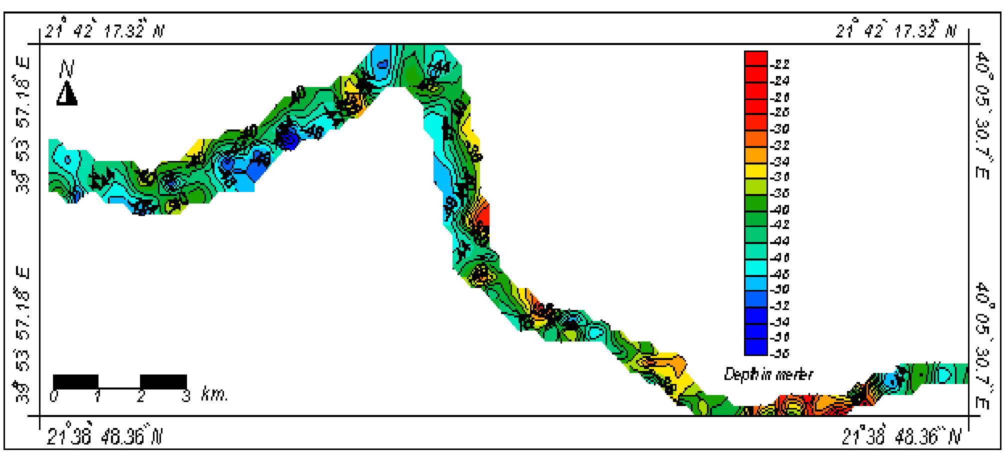


Fig. 14: Depth contour map as deduced from ground magnetic survey, wadi Bany Omair.

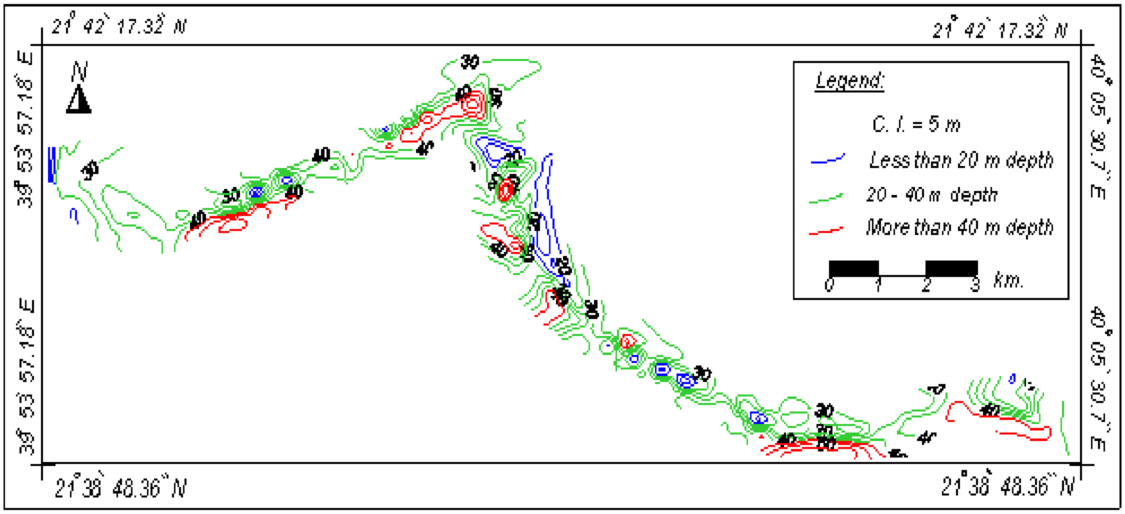


Fig. 15: Depth contour map to basement as deduced from VES survey, wadi Bany Omair.

Table 2: Summary of the VES survey results in wadi Bany Omair

S.N	VES No.	Coordinates						Depth to Water Table (m)	Depth to Bed-Rock (m)		Thick. of Saturated Zone (m)
		N			E				Res.	Mag.	
1	5	21^0	39'	14.2"	40^0	02'	54.8"	16	41.4	44	25
2	6	21^0	39'	8.7"	40^0	02'	37.4"	21	38.3	36	15
3	11	21^0	39'	13.9"	40^0	01'	10.9"	30	41.2	43	11
4	17	21^0	40'	16.3"	39^0	59'	9.1"	35	50	42	7
5	19	21^0	40'	55.9"	39^0	58'	43.2"	35	51.7	46	11
6	20	21^0	41'	9.3"	39^0	58'	42.2"	35	48	46	11
7	21	21^0	41'	24.3"	39^0	58'	37.7"	37	54	47	10
8	26	21^0	42'	11.6"	39^0	57'	55.5"	37	60	50	13
9	27	21^0	42'	8.3"	39^0	57'	41.8"	37	51.5	50	13
10	35	21^0	41'	12.1"	39^0	55'	20.7"	30	30.5	34	0.5
11	37	21^0	41'	5.4"	39^0	54'	47.3"	35	43.5	44	8.5
12	44	21^0	39'	4.6"	40^0	02'	39.3"	20	38.3	40	18
13	48	21^0	39'	17.8"	40^0	01'	2.6"	30	45	48	15
14	53	21^0	41'	7.6"	39^0	55'	32.1"	30	57	55	25
15	54	21^0	41'	12.5"	39^0	55'	26.7"	30	64	56	26
16	63	21^0	39'	10.5"	40^0	04'	22.3"	23	48	-	25
17	71	21^0	41'	2.1"	39^0	58'	42.o"	35	55	44	9
18	73	21^0	41'	34.2"	39^0	58'	42.8"	36	50	47	11
19	74	21^0	42'	15.2"	39^0	58'	15.0"	37	65	50	13
20	85	21^0	39'	28.4"	40^0	03'	30.4"	25	44	46	19
21	87	21^0	39'	22.2"	40^0	03'	28.8"	26	48	46	20
22	90	21^0	39'	55.5"	40^0	00'	10.8"	-	40	42	-
23	96	21^0	40'	12.6"	39^0	59'	16.7"	35	50	57	15
24	97	21^0	41'	24.1"	39^0	58'	36.6"	27	68	48	21
25	102	21^0	40'	23.4"	39^0	59'	7.6"	35	51	43	8

Accordingly, the resultant iterative resistivity models for the total 106 soundings consists of six layer, however the first look on the curve types could classify most of them into four layers. The absence of actual well logs in the study area, led the interpreter to take into consideration the geological background of the area.

In order to facilitate the interpretation, 24 subsurface true resistivity and geoelectric cross section were graphically constructed along and across the wadi. Figures 11 and 12 are selected examples for these sections. In this regard, the authors follow Bisdorf (1982), who stated that the resistivity cross sections are generated from individual sounding interpretations. Each sounding interpretation is sampled in a manner to approximate a continuous vertical distribution of resistivity with depth. These vertical distributions are then horizontally interpolated to create a grid. Colours are assigned based on the interpolated resistivity values and the desired contour levels. Triangles on the upper surface of the cross section designate the sounding locations.

In spite of most soundings have models more than four layers, the first three surficial sub-layers have high to very high resistivity values and small thickness. However, the interpreter could group them as one layer to reduce the number of layers into the minimum. The thickness of near surface Quaternary sediments differs from place to another in the wadi. Therefore, it was expected that these deposits have different resistivity values which reflect weather they are wet or dry and reflect also the composition and grain sizes. This variation in the resistivity value of the wadi sediments may be due to the presence of weathering products of the surrounding resistive materials and transported hard rock fractions.

The results reveal that the surface layers consist of wadi sediments which are composed mainly of clays, sand and rock fragments in certain parts. These sediments are derived from the erosion of the country rocks, having high resistivity values. The low resistivity values of the third layer which comfort on bedrock refer to a water-saturated layer. The large thicknesses of the sedimentary cover provide promising sites.

The depth to basement, thickness of the water-saturated zone and the best fit curves were the bases which were taken into consideration to evaluate the sounding results. Best fit promising soundings (25 in total) were chosen, based on geophysical output (Figure 13). The locations of these soundings Nos. 5, 6, 11, 17, 19, 20, 21, 26, 26, 27, 35, 37, 44, 48, 53, 54, 63, 71, 73, 74, 85, 87, 90, 96, 97 and 102 are shown in table 2. These promising soundings are chosen away from possible site influences that may distort the results as well as sites that have displayed maximum depth to the basement and possible water bearing potential.

Basement Depth Calculations

The calculations of the ground magnetic (table 2) are presented in a contour map (Fig. 14) which can be viewed as three zones, in which the shallow first zone shows depth to the bed-rock at less than 36 m. This zone is the predominant one occupies parts especially the east and the centre and limited parts of the west. Zone two relates to mean depth levels ranging from 36 to 46 m and covers large parts along the wadi. Zone three lies at the southwestern section of the area, some parts of the west central region and limited parts in the east. The significance of this zone lies in its depth (> 46 m) which indicates thick sedimentary cover.

Examining the basement depth map (Fig. 15), which is based on the results of the electrical sounding taken in the wadi, refers that the area can be subdivided also into three zones. The first one covers several locations specifically in the middle where the basement is shallowest (less than 20 m) and the average depth is calculated as 13.8 m. The second zone covers vast parts in the area, including areas east, central and western parts and is characterized by depth between 20 and 40 m (average 31 m). The third zone is scattered in limited parts and represents the deepest parts (> 40 m) with average value of 47.3 m. Comparison between the results of the calculated depth to the basement by the two methods (Figs. 14 and 15) shows a considerable agreement between them.

CONCLUSIONS

The application of the power spectrum analysis on the magnetic data of the area proved the presence of two main average interfaces at 41 and 129 m for the residual and regional components respectively. A mean value of 42 m represents large proportion of the calculated stations in the study area. Generally, the depth to the basement increases westwards and decreases towards the east. There are variations in the depth to the basement in the central parts which indicate deep basement in certain parts.

The VES survey indicated that the thickness of near surface Quaternary sediments differs from place to another in the wadi and consist of wadi sediments which composed mainly of clays, sand and rock fragments in certain parts. These highly resistive sediments are derived mainly from the erosion of the country rocks. The third layer (Quaternary sediments) is characterized by low resistivity referring to a water-saturated layer. The depth to basement, thickness of the water-saturated zone and the best fit curves were factors taken into consideration to evaluate the sounding results. Accordingly, a total 25 VES were chosen as promising sites for ground water potentialities; they are VES's 5, 6, 11, 17, 19, 20, 21, 26, 26, 27, 35, 37, 44, 48, 53, 54, 63, 71, 73, 74, 85, 87, 90, 96, 97 and 102. The calculated depths from the resistivity methods proved also that the depths to the bed-rock increase generally towards the west. The integration of the results of the two methods shows considerable agreement between them.

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