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GROUND WATER POTENTIALITIES OF WADI MALAKAN- SOUTHERN MAKKAH ALMOKARAMAH CITY, SAUDI ARABIA

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إمكانيات المياه الجوفية فى وادى ملكان جنوب مكة المكرمة بالمملكة العربية السعودية

الخلاصــة: لقد تمت دراسة وادى ملكان بإستخدام طرق جيوفيزيقية متعددة بغرض تقييم الخزان الجوفى بالوادى ومن خلال تحليل بيانات المغناطيسية الجوية والأرضية أمكن تحديد أعماق وإتجاهات التراكيب الجيولوجية التحتسطحية السائدة بالمنطقة والتى تتحكم فى مسار جريان المياه الجوفية. أما طريقة المسح الجيوكهربى فقد أوضحت أن هناك أربع طبقات جيوكهربية تحتسطحية مختلفة،الطبقة الأولى تتكون من رواسب الوادى الجاف الموجودة على السطح وتتكون من كسر صخرية ورمل وطين والطبقة الثانية عبارة عن الصخور الجافة، تسفلها طبقة رملية غرينية والطبقة الثالثة هى طبقة حاملة للمياه، أما الطبقة الرابعة السفلية تمثل طبقة صخور القاعدة وهى طبقة جافة جداً وغير منفذة. وبناءاً على نتائج التحليل الكيميائى لعينات المياه فقد تم التوصل إلى أن درجة الملوحة تزداد فى اتجاه الغرب مما يوضح أن نوعية المياه تصبح أقل جودة كلما اتجهنا غرباً وربما يعزى ذلك إلى أن اتجاه الجريان من الشرق إلى الغرب وبالتالى مع إذابة الأملاح من الصخور يزداد تركيز الأملاح المذابة فى المياه الجوفية حتى تصل إلى أعلى ما يكون فى الجزء الغربى من منطقة الدراسة. وهذا يوضح أن المياه الجوفية بالوادى تتعدى الحدود المسموح بها للشرب بينما من الممكن استخدامها فى رى المزروعات وزراعة بعض المحاصيل التى تتحمل درجة الملوحة المتوسطة.

ABSTRACT: *Wadi Malakan area has been studied using an integrated approach for estimating the ground water potentialities. Using satellite imagery, the direction of water flow, drainage system and the most appropriate locations for the presence of water has been identified in the region. Land- and aeromagnetic maps showed that the subsurface structures include faults and dykes. These structures take different directions; the northeast, northwest as well as north-south and east-west which indicate that the area occurred under the influence of different tectonic movements. The calculated depths using Fast Fourier transform (FFT1D) reveals that, the average depth for deep sources ranges between 27.5 to 58 meters while for shallow sources ranges between 4 to 14.5 meters. 2D modeling was also carried out for the magnetic data to clarify the subsurface structures and the depth of basement rocks. Thirty of Vertical Electrical Soundings (VES) and eight of geoelectrical cross-sections have been carried out and showed that, the area has four geoelectrical layers; the first layer consists of rock fragments, sand and clay; second layer is of dry rocks, the third is sandy alluvial layer (water-bearing layer), while the fourth one represents the basement rock and is very dry and non-permeable.*

According to the results of analysis for water samples, it has been reached that value of electrical conductivity is moderate in the eastern part and increases to the west also the salinity of water increases to the west. Well no.13/7 (to the west of the study area) shows abnormal values with respect to other wells for the main components especially chloride, sodium, sulphate and calcium. This indicates that the main elements are much higher than the allowable standards for drinking water globally and the water quality becomes less tends to the west due to the concentration of dissolved salts in the groundwater. Finally, it can be concluded that, the groundwater of wadi Malakan exceeds the permissible limits for drinking while it could be used to irrigate crops some crops which can bear moderate salinity with extreme caution when dealing with the well no. 13/7 with relatively high salinity. The better locations for drilling are at vertical electrical soundings (VES) No. 1, 2, 3, 4, 5, 6, 7, 14, 15, 25, 22, and 20.

INTRODUCTION

The study area lies to the south of the city of Makkah, and away from Makkah's holy shrine about 35 km. The significance of the study comes from the importance of the city of Makkah, from the religious aspect of Muslims, where they arrive in large numbers throughout the year to this sacred spot. The city of Makkah, one of the most important cities in Saudi Arabia, has expanded vertically and horizontally and this led to the failure of some service sectors with this growth. The increasing of population in the city as well as increasing the number of pilgrims to the Holy House led to increase in the consumption of both desalination water and groundwater. Makkah city was adopted in the past to get groundwater from wades around, and some springs (e.g. Ein Zubaydah). This has been sufficient when the water requirements were limited, but after the great urbanization that occurred in Makkah and the increasing numbers of people, pilgrims and visitors significantly, the government of the Custodian of the Two Holy Mosques started to deliver water desalination to Makkah. In addition to the Ministry of Water and Electricity fetching water from some wades surrounding Makkah. The Ministry of Water and Electricity supported and funding some scientific projects for water resources in the area of Makkah and recommended the highly need to study the water possibilities in Wadi Malakan and wadi al-Husseinieh. Furthermore, the previous studies (Al-Dekhail et. al., 1997) have recommended that there are good prospects for groundwater in wadi Malakan and its stock water not consumed and promises of stock aquifer believed to be exceeded those stored in Wadi Ibrahim.

LOCATION

Wadi Malakan located in the southern part of the city of Makkah, near the mouth of the Wadi Ibrahim and wades of Aranh - Numan within the administrative boundaries of Makkah. There are sources of wadi nutrition near Taif Governorate passing near the town of Makkah, breaking number of provinces and districts, such as Algemom reaching to Jeddah Province on the Red Sea Coast. The study area extends (Fig.1) between latitudes 21^{o} 07$'$ and 21^{o} 09$'$ North and longitude 39^{o} 40$'$ and 39^{o} 48$'$ East including the main part of the wadi Malakan and can be accessed through the way of non-Muslims.

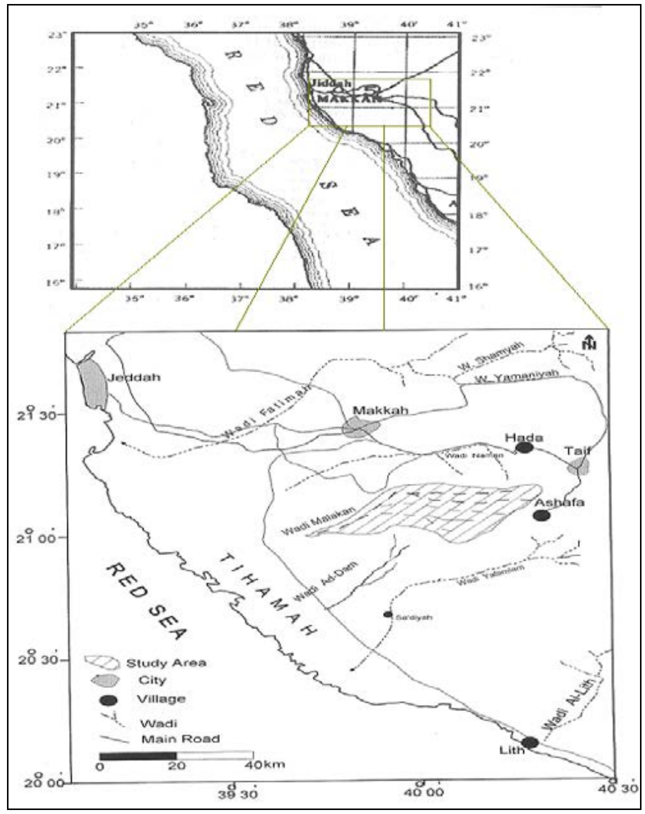

Fig. (1): Location map for the study area (Subyani et al. 2004).

GEOLOGICAL SETTING OF WADI MALAKAN

The elevation of study area ranges from 120 -180 meters (above sea level) while its width ranges from 500 to 1200 meters. It is clear that the runoff groundwater in wadi Malakan is generally to the west towards the Red Sea. The Arabian Shield rocks cover the western part of Saudi Arabia except the coastal plain, and some limited sedimentary basins while the eastern part covered by platform sediments. Pre-Cambrian rocks in Makkah are subjected to several distortions and their results are in the form of faults, folds and transformation (Fig.2) with different degrees mostly to green facies. Sedimentary rocks of tertiary were cracked and tilted slightly. The axes for folding are NNE and NNW (Moore & Al-Rehaili, 1989). Recent sediments cover more than a third of the area and the rest covers with Pre-Cambrian rocks. Siltstone which encountered in southwest and northwest of Wadi Mulkan area is part of Alschmisi formation. Alschmisi rocks lies unconformably on the Arabian Shield and varies from 74 to 183 meters (AlShanti, 1966). The lower part consists of sandstone with some layers of mud; the middle part consists of sandstone layers separated by heimataite, while upper part is composed of mudstone, silt and volcanic ash. Quaternary sediments can be classified into alluvial, wadi deposits and sand dunes.

There are seven faults in the study area and all belong to the region of Makkah (Moore & Rehaili, 1989) and ranges from 2 to 3 km in length. Some faults are extending in the direction of NNW and interrupt the complex. Other fault extends NE at central and south wadi Mulkan mountains near Safran and Sadein follow the same trend of faults (Transform Fault) of the Red Sea. In the southwestern corner of the study area, there are crack extends northwest and west and represents the demarcation line between Alschmisi (Siltstone and Tuff) and the basement complex (Biotite, granodiorite and monzogranite).

GEOPHYSICAL DATA ACQUISITION

Magnetic method has been applied in this study to define the main subsurface geological structures and the depths to the basement rocks. The detailed magnetic field measurements carried out along 13 magnetic profiles. 12 profiles are crossing the main stream of Wadi Malakan with lengths range from 490 – 1530 m and station interval 10 m while, the last one was parallel to the main stream with total length 5000 m and station interval 10 m (Fig. 4).

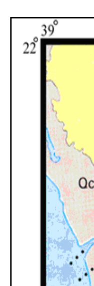

Fig. (2): Structures around the city of Makkah (Moore and Al-Rehaili , 1989)

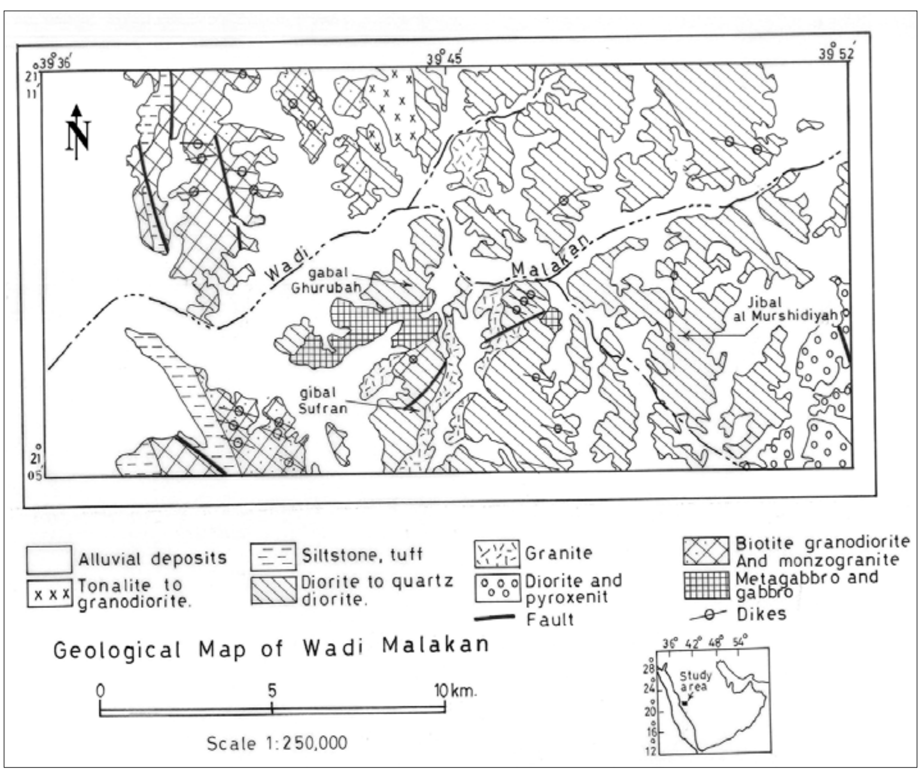

Fig. (3): Geological map Wadi Malakan area (Moore and Al-Rehaili, 1989).

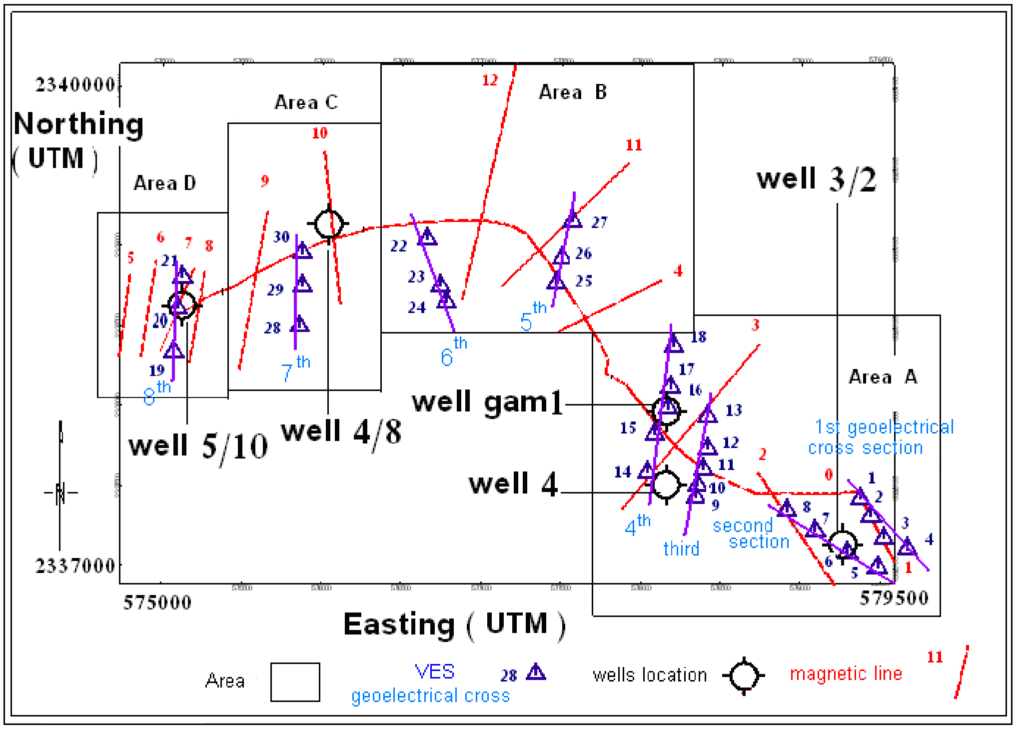

Fig. (4) Field measuring lines of Magnetic and electrical survey in Wadi Malakan.

The area was divided into four sub-areas (A, B, C, and D) and magnetic data were acquired using land magnetometer (G858 Model of Geometrics) equipped with MagMap software to transfer the collected data into the computer and GPS instrument to define the coordinates of each measuring point.

The subsurface water-bearing zones can be detected using electrical method. Schlumberger array was carried out in the Vertical Electrical Sounding (VES) for measuring the electrical resisitivity values for subsurface layers, where this type of survey reveals the changing of electrical resistivity values with depth. Schlumberger tool is the best and widespread one for this type of studies (Telford et al., 1990 and Reynolds, 2000) and required from 10 to 20 readings of changing distances with respect to the central point of measurements according to the following equation.

$$AB \geq 5\ MN \qquad (1)$$

Where AB is the distance between the current electrodes, and MN is the distance between the potential electrodes

There are eight cross-sections have been carried out and covering the whole area of study and each of these sections includes many measuring points (Fig. 4); the first four cross-sections located within the area (a); the 5th and 6th cross-sections within area (b); the 7th one lies inside area (c); the last (8th) one located inside area (d). Thirty of VES were measured to define the depths of groundwater zone, geological and hyrogeological conditions for the subsurface layers. The locations of VES were selected near to the magnetic cross-sections and according to the distribution of VES with the optimum distances leads to construct contour map reflect the changes of resistivity values for subsurface layers. The electric field measurements were collected using ELREC-T (BRGM model) instrument which equipped with both of receiver and transmitter units. The greatest distance between the electrodes (in Schlumberger arrays) have reached 300 m. 14 of the measuring points were taken at distances (AB/2) equal to 15, 10, 3, 6, 60, 40, 30,20,80,100,150,200,250, and 300m where MN/2 equals to 2 meters at distances of 3,6 and 10 meters; MN/2 equals to 10 meters at distances 15, 20 and 30 meters; MN/2 equals to 20 meters at distances of 60, 80, 100, 150, 200 meters; and MN/2 equals to 40 meters at distances of 250 and 300 meters.

DATA PROCESSING

1. Magnetic Data Processing

The recorded magnetic data were transferred using MagMap program and the processing sequence has been applied; removing the impact of changes in magnetic field intensity of the ground during the daytime activity resulting from magnetic storms, the impact of the ionosphere and Diurnal Correction. Any daily correction is read directly at the base station and gives the correction necessary to add or subtract from the measured value at the same time; moving average 3-points method for smoothing of recording magnetic data was used for each line separately, as they were given the best results in the removal of noise and random errors; and conducting contour map for the corrected values in a series of parallel lines.

Montaj^{TM} Oasis program (version 6.2, in 2006) has been used to address magnetic data and two dimensional mapping. According to Keller et al., (1985) and Lidiak et al., (1988), there are several techniques to separate the magnetic anomalies. One of these techniques so-called Fast Fourier Transform (FFT) that improves the location of shallow structures in addition to high-Pass filter, downward continuation, Low Pass filter and upward continuation. The following steps have been applied for the magnetic data processing; conducting the total magnetic map for the corrected data and Reduced To the north magnetic pole (RTP). Two dimensional modeling techniques were applied using GMSYS-2D program (Northwest Geophysical Associates) to define the subsurface crustal structures and upper mantle.

2. Geoelectrical data

Thirty of Vertical Electric Sounding (VES) readings have been implemented at the places of magnetic field measurements to measure the true resistivity values resulting from subsurface layers under each VES. Eight of subsurface geoelectrical cross-sections were constructed and showing the changing of electrical resistivity with depths profiles. These cross-sections show the rock distribution under the earth's surface, the depth of groundwater and basement rocks. Both of RINVERT and IPI2W Software have been used to address the obtained electrical resistivity data.

DATA INTERPRETATION

a. Linear structures

The structures are straight lines or slightly curved and of geological origin can be seen from the space image in the form of straight or almost straight from the wadi course. The terms synthetic break or discontinuity in the crustal rocks and can happen in any direction and different lengths (Rajab, 1989). The relationship between linear structures and the presence of groundwater depends on the porosity and density of rock fractures that are secondary permeability of rocks, making them highly efficient tool to collect surface water and leakage to the groundwater reservoirs. Studies have shown that, the increased intensity of cracks and fractures and locations of weakness in the Earth's crust and phenomenon in the form of linear structures can be relied upon to designate sites that are high permeability help to hunt rocks and compiling groundwater. Structures take basic direction of the northeast as well as north-south and east-west directions of the same faults in the Red Sea (Fig.5). Using Rose diagram representation of the distribution attitude relative density of longitudinal and transverse structures (Fig.6)

b. interpretation of the magnetic results

1. Interpretation of aeromagnetic data

The corrected aeromagnetic data has been used to construct the total aeromagnetic map using Oasis Montaj software (Fig.7). Then, it is reduced to the north magnetic pole (RTP) using inclination angle of $29^o.6105$ and deviation angle equal to $2^o.693$ (Fig.8) to identify the regional geological Structures for Makka including the study area. The definition of exact locations of faults depends on: the sudden changes in the direction of magnetic anomalies and the gradient value of contour lines (closely spaced contour); both of horizontal and vertical displacements that followed the faults; the changing of the magnetic properties such as: shape of contour lines, their trends, spacing distance, and the intensity of magnetic anomalies can serve as an evidence for faults, where this fault separates between magnetic domains with different properties.

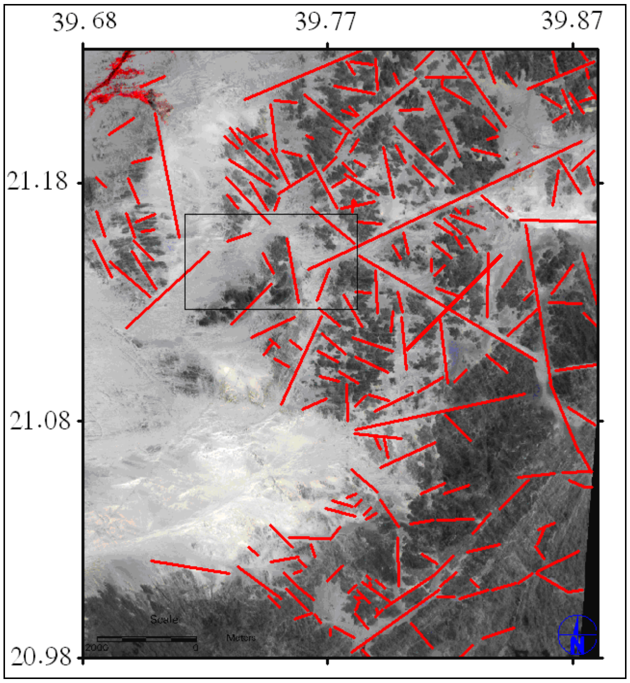

Fig. (5): Structural lineaments from space image for study area

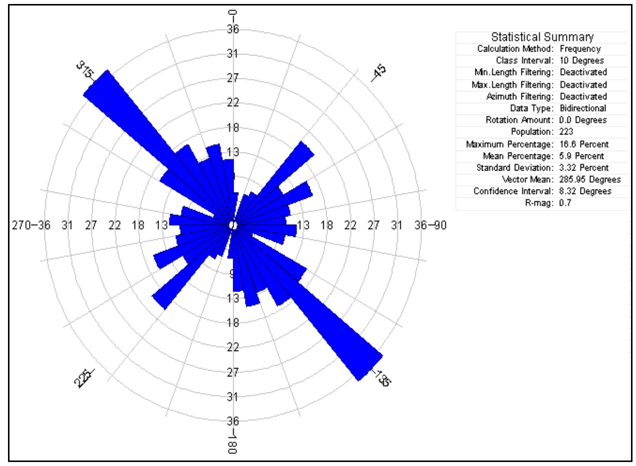

Fig. (6) Rose diagram for the linear structures.

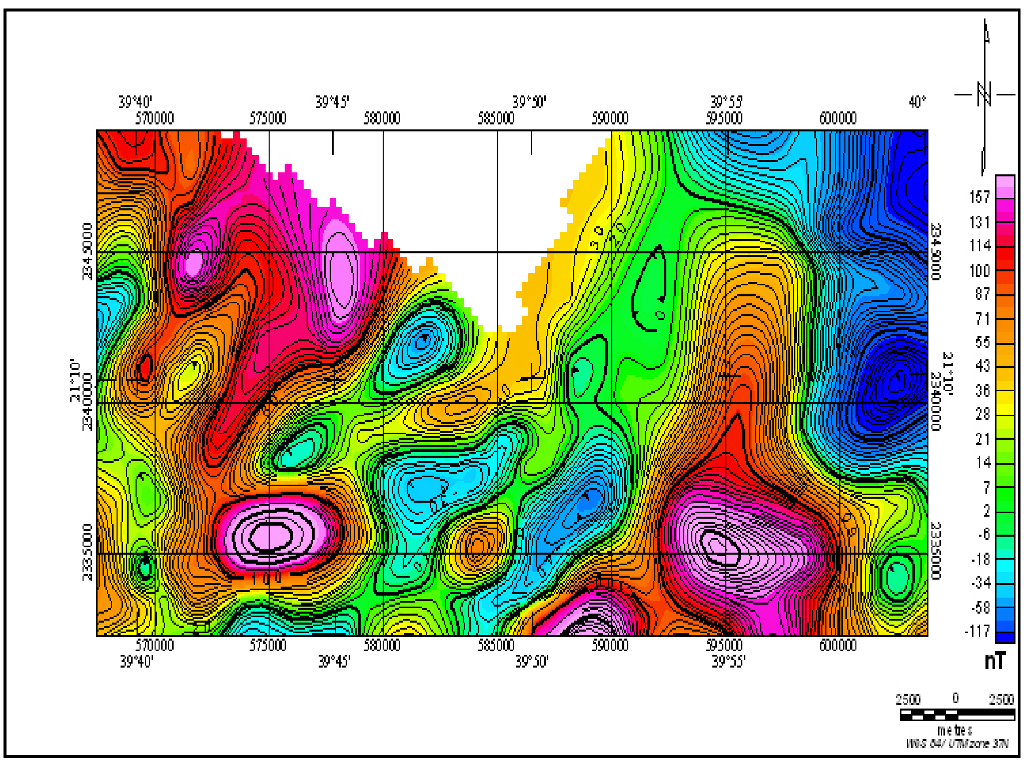

Fig. (7): Aeromagnetic total intensity map for Wadi Malakan area.

The main structural trends can be identified from RTP map as follows; 1) both of magnetic anomalies and steep-slops contour lines trends mostly in the northeast direction the same trend for the transform fault of the Red Sea, which emphasizes that most geological structures in the region are concentrated along this trend. 2) Faults take several directions, but it is less widespread than the previous trend, some of them take the northwest of the same Red Sea direction, while other structures take the north-south and east-west directions. Low magnetic values in the map (L) represents either non-magnetic rocks or geological structures with low magnetic susceptibility (basins contain sediments) or presence of acidic rocks. While high values (H) represents the basement rocks. The moderate intensity values between negative and positive in the map indicates that, most of rocks have moderate intensity and the trends of contour lines vary from site to another. This map shows various shapes of magnetic anomalies: circular, linear and non-regular which reveals different sources. Magnetic map shows some correlation with the geological map of Makka for most of faults.

2. Interpretations of the land magnetic data

Total land magnetic contour map has obtained after processing of the magnetic data for the area (Fig. 9) and then Reduced to the Pole (RTP) map (Fig. 10). RTP map can be classified into four small areas (from a to d) as follows;

Area (A):

The presence of low magnetic anomaly at the beginning of the study area in the southeastern part of area (a), where it ranges between 40050 and 40225 nanotesla. This indicates that the presence of a significant thickness of sediments with a length of 550 meters and width of 2155 meters. The anomaly begins to increase due north where the highest value reaches 41055 nanotesla with length of 1170 m and 885 in width. The higher value indicates the presence of geological structures with high magnetic susceptibility (basement rocks) close to the earth's surface and several faults trending northwest, northeast and east -west.

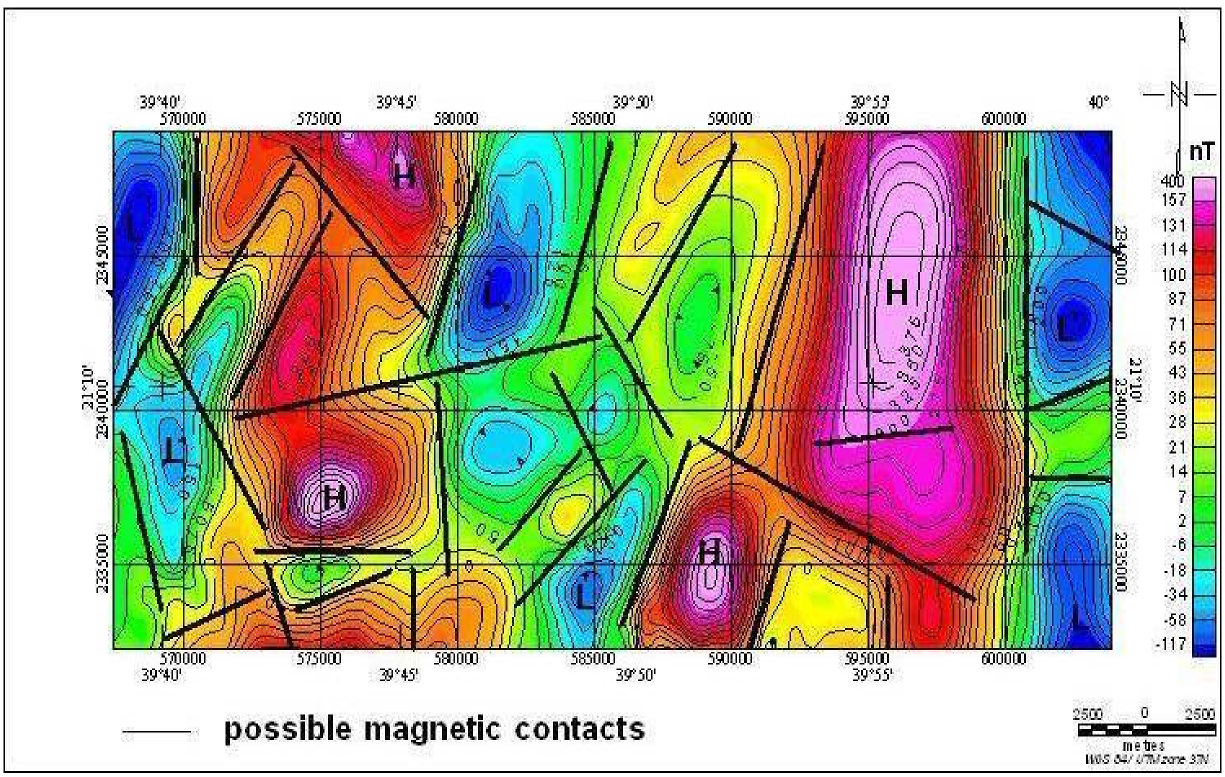

Fig. (8): RTP map for the study area.

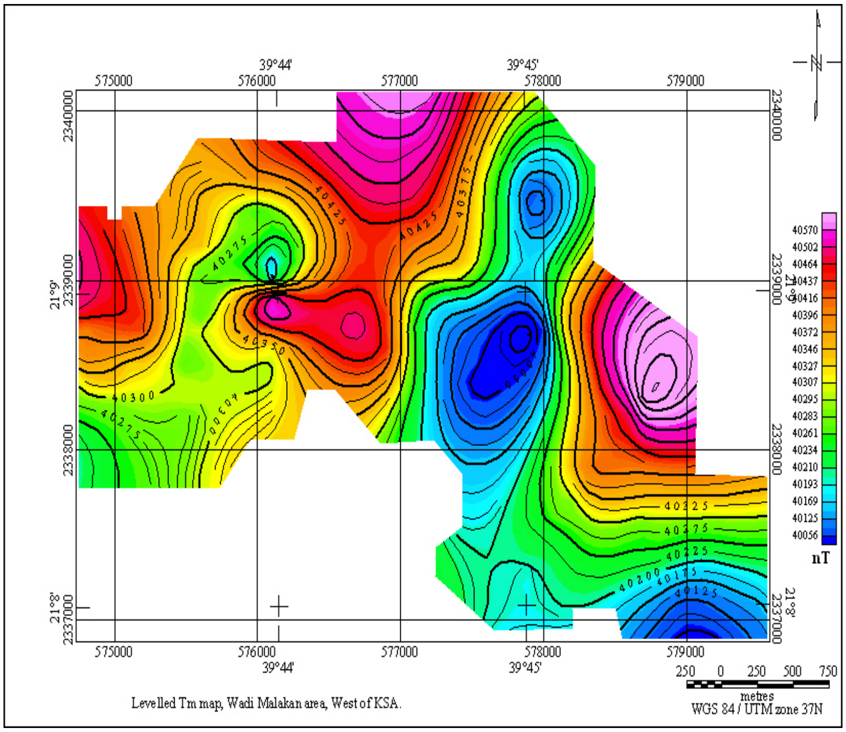

Fig. (9): Total land magnetic intensity map.

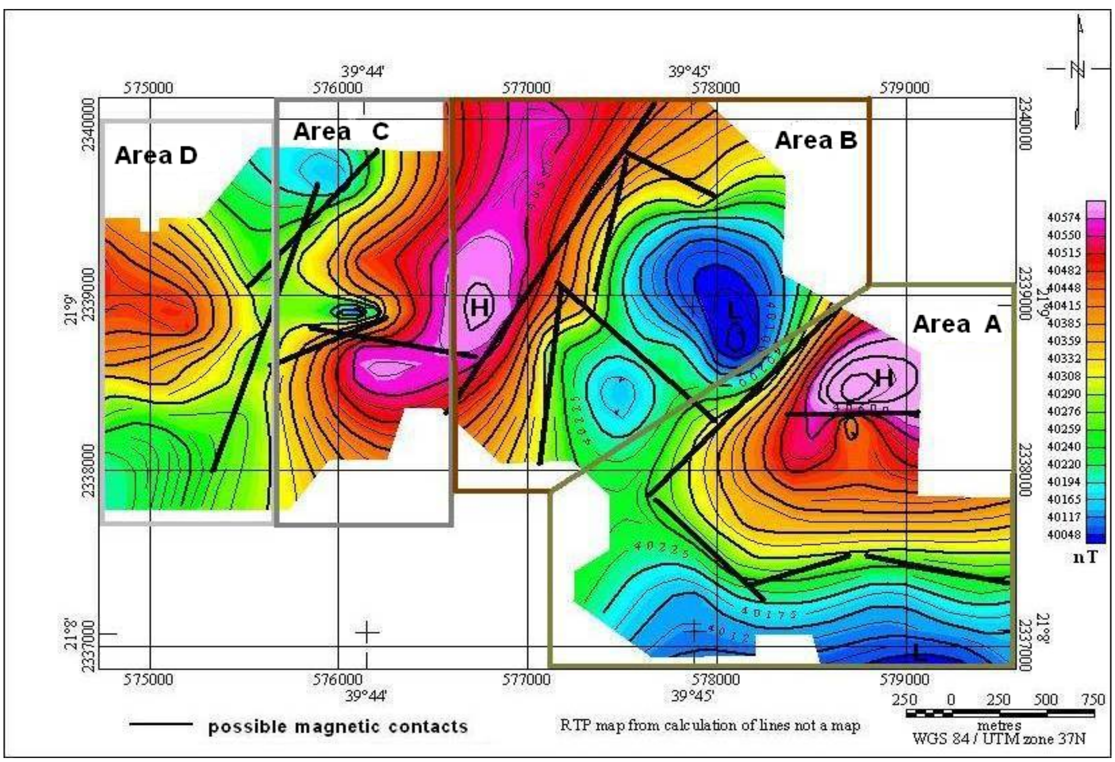

Fig. (10): RTP map for the total land magnetic field measurements.

Area (B):

The presence of low magnetic anomaly (ranges from 39950 to 40299 nanotesla) indicates the presence of large-scale thickness of sediments with a length of 980 m and 1010 in width. The magnetic value increases towards the west and northwest where the highest value reaches 40819 nanotesla with length of 1763 m and 624 meters in width represents near-surface basement rocks and several trends take northeast at the center of the map, and northwest and north – south as well.

Area (C):

It is noticed at the beginning of this area that, the presence of high magnetic anomaly (40650 nanotesla) with total length of 1621 meters and 1027 meters in width presents the basement rocks. It begins to decrease slightly till the presence of low magnetic anomaly with a small length of 117 m and 233 m in width which represents the sediments of small size and there are several faults trending northeast and east-west.

Area (D):

There is moderate magnetic anomaly at the beginning of the area D and increases towards the west direction, as well as the faults take northeast direction.

Based on the detailed interpretation for the RTP map, four structural trends have been identified as follows: 1) most of magnetic anomalies with steep-slop contour lines trend mostly to the northeast (the same trend of the Red Sea transform faults). This indicates that, most of geological structures in the region are concentrated along this trend. Northeast faults represent either the oldest (pre-Cambrian) continental faults of Hejaz-Asir active trend and rejuvenated during the Tertiary, or transform faults recently formed as a result of the opening of the Red Sea. 2) The second trend of the faults takes northwest (the same Red Sea fault trend) but less widespread than NE trend and controlled the sedimentary basins of Tertiary. 3) Group of faults oriented east-west and it is old and continental faults. 4) Few faults trending north-south and effected by the northeast faults. The presence of this group of different directions indicates that, the study area has been subjected to multiple tectonic movements led to the breaking of rocks in this way; in addition to the rejuvenation movements along the old trends, leading to the emergence of some of those faults once again. It is clear from the map that, the areas of A and B are the best locations for Vertical Electrical Sounding (VES) due to the presence of low magnetic anomalies and this means the presence of large thickness of sediments.

1 modeling of the magnetic cross sections:

GMSYS-2D program for modeling has been used to clarify both of the subsurface geological structures and depths of different layers along magnetic line No. 0 that extends along Wadi Malakan from east to west with total length of 5000 m (Fig. 11). It is noticed that, the upper layer composed of sediments and extends to depth approximately of 250 m. It also shows that, the basement rocks affected by two faults; the first one takes northeast direction and separates Block1 with susceptibility of 0.0005, Block2 with susceptibility equal to 0.0006, as well as the presence of sedimentary basin in the middle of the line. Other sedimentary basin was found behind the second fault which trends northwest and separates B2 and B3, where susceptibility is equal to 0.0007. It believes that the area occurred under the influence of tectonic movements, which led to a presence of these faults.

While the magnetic line No. 10 (Fig.12) extends from the northwest and southeast has total length of 940 meters and cross the main stream of wadi Malakan. As shown that, the first layer composed of sediments with depth up to 260 m. While, the underlying basement rocks has number of objects; b1 with magnetic susceptibility; b2 with magnetic susceptibility equals to -0.002; b3 with susceptibility and equals to 0.009; b4 with susceptibility equals 0.004 and b5 with susceptibility of – 0.007. The presence of igneous dyke at distance 660 meters from the beginning of the line and interrupt the basement rocks with susceptibility equals -0,063 and separates between b5, b6 where the susceptibility of b6 is 0.013 and crustal with susceptibility equal to 0.001.

7 interpreting the results of geoelectrical measurements

Area (a):

Eighteen VES has been carried out in this area (Fig. 13 as example) and results indicate that, there are four subsurface geoelectrical layers in this area; the first layer represented by dry deposits and consists of sandstone and gravel. It extends to a depth ranging from 2 to 4 meters with resistivity value ranges from 103 to 240 Ohm-m; the second layer consists of dry rocks with depth ranges between 4 to 10 meters and resistivity between 250 to 350 Ohm-m; the third one is sandy alluvial layer and it is the water-bearing layer at this area with depth ranges from 10-43 meters and resistivity ranges from 16 to 68 Ohm-m, and the fourth one is the basement rock at depths ranging from 43 to more than 99 meters and the resistivity ranges between 553 to 6814 Ohm-m.

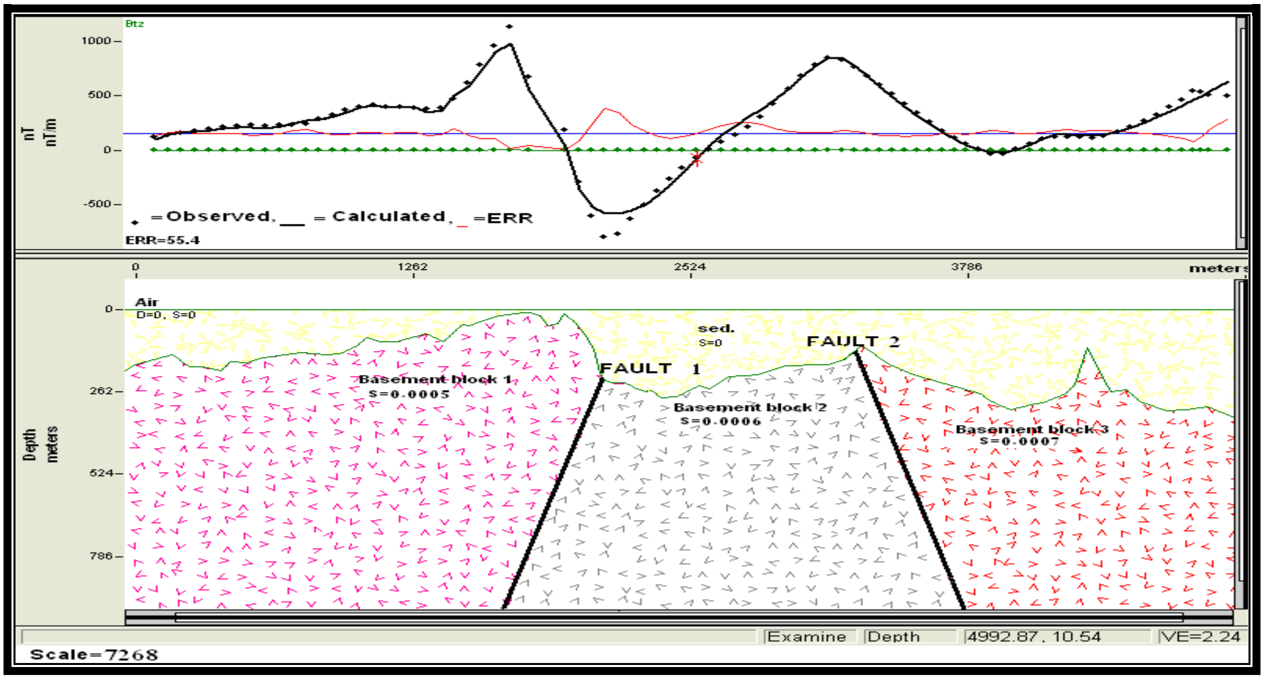

Fig. (11) Modeling of longitudinal magnetic line No. 0.

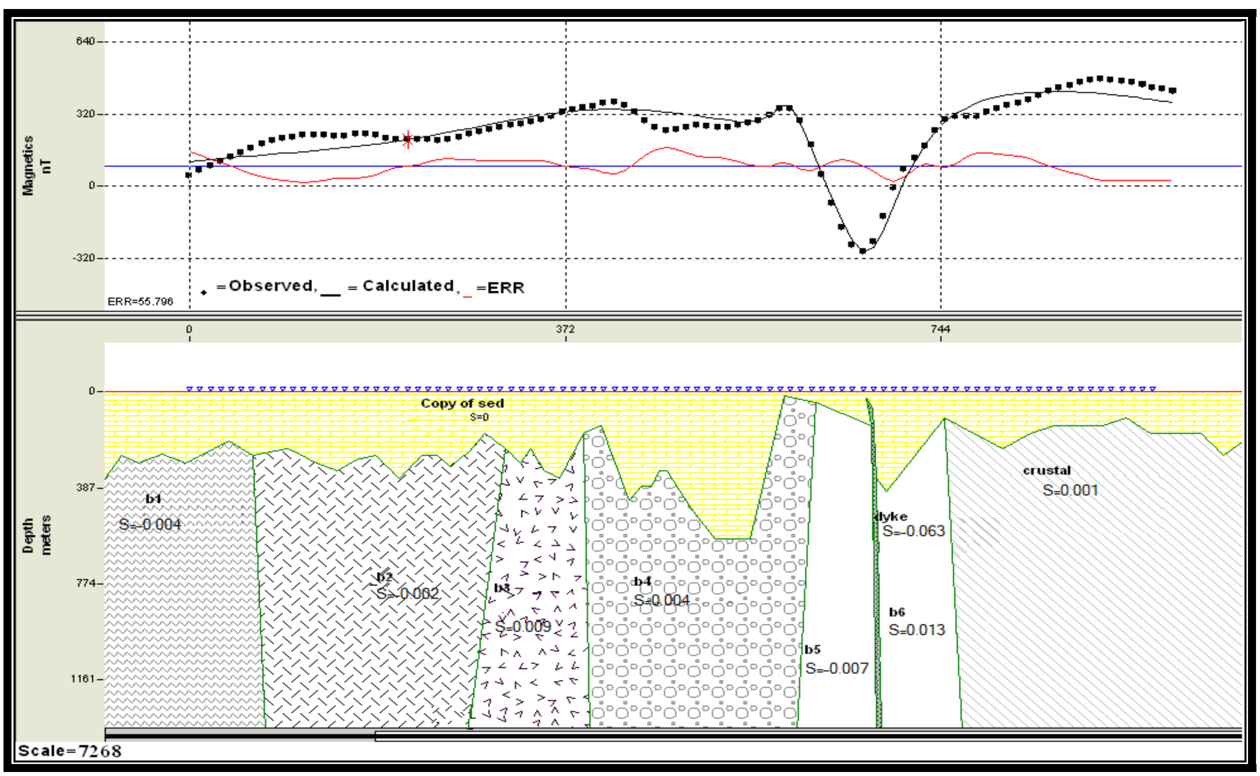

Fig. (12) Modeling of transverse magnetic line No. 10.

The first geoelectrical cross section (connects VES No. 1, 2, 3 and 4), occupies the eastern edge of the study (area a) and perpendicular to the main stream of Wadi Malakan with length of 400 m (Fig.14). This section shows the presence of upper layer with a uniform thickness and relatively high resistivity ranging between 100 and 170 Ohm-m. It is followed by dry layer with uniform thickness, except under VES no. 1 where the thickness increased; with resistivity up to 250 Ohm-m and the average thickness of this layer is about 20 m. The third layer is of low resistivity of 55 Ohm-m with average thickness of about 30 m. Its thickness becomes small under VES no. 2 while increasing up to about 45 m under the VES No. 1, 3, 4. It represents the weathered layer and believed to be the water-bearing layer with high salinity based on the chemical analysis of water samples. The fourth layer has high resistivity ranging from 250 to more than 400 Ohm-m. Its depth equals about 55 meters and declined slightly under VES No. 4 and No. 1 and it is dry rocks and non-permeable basement rock.

Area (b):

There are six VES located within this area (Fig. 15 as example) and demonstrate the presence of three geoeletrical layers at area b; 1st layer very dry sediments of sandstone and gravels. It has depth ranging from 3 to 10 meters with resistivity ranges between 103 and 250 Ohm-m; the 2nd layer is sandy layer and the water bearing layer with depth ranges from 10 to 12 meters and resistivity ranges from 16 to 68 Ohm-m; the 3rd one represents the basement rocks which is very dry and non-permeable and extends to depth ranges from 22 to 81 meters with resistivity ranges from 553 to 6814 Ohm-m.

The 5th geoelectrical cross-section (Fig. 16) includes VES No. 25, 26 and 27 and located within area (b) perpendicular to the direction of the main stream of Wadi Malakan. It extends with length of 200 m from southwest (VES No. 25) to northeast (VES No. 27).

This section shows, upper layer of wadi deposits with uniform thickness and relatively high resistivity up to 100 Ohm-m. This layer is dry layer with variable thickness where increases northeast till reach the highest thickness under VES no. 27. The second layer of least resistivity (less than 30 Ohm-m), the highest thickness is under VES No. 25 and noticed that the thickness of this layer decreases towards the northeast till disappeared under VES no. 26 and 27. This layer represents sandy alluvial deposits and it is believed to be the water-bearing layer with high saline water. The third layer represents basement rocks of dry and non-permeable nature and has high resistivity up to more than 200 Ohm-m at depth of about 35 meters.

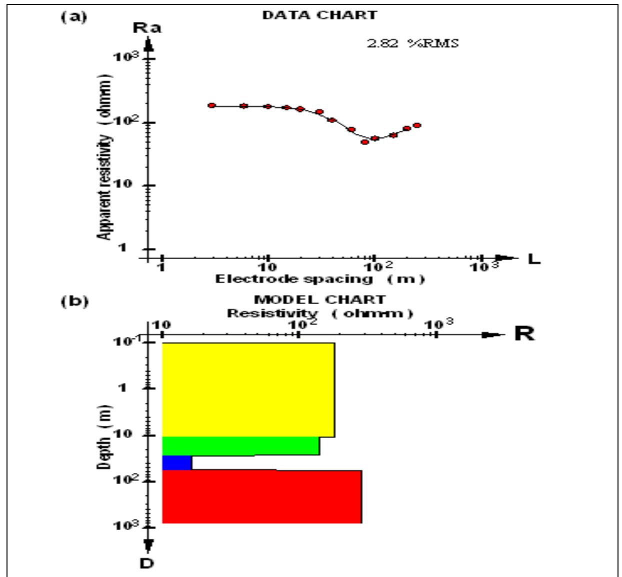

Figure 3. *Inverse modelling for sounding <VES2.dat> - Schlumberger array at "VES2".*

Layer	Depth (m)	Thickness (m)	Resistivity (ohm·m)	Thick/Res (1/ohm)	Thick*Res (ohm·m²)
1	0.000	10.898	179.973	0.061	1961.374
2	10.898	15.866	141.588	0.112	2246.481
3	26.764	28.718	16.387	1.753	470.589
4	55.482	INFINITY	281.995	-	-
			TOTAL:	1.925	4678.444

Table 3. *Inverse modelling for sounding <VES2.dat> - Schlumberger array at "VES2".*

Fig. (13): location of VES no. 2 within area (b).

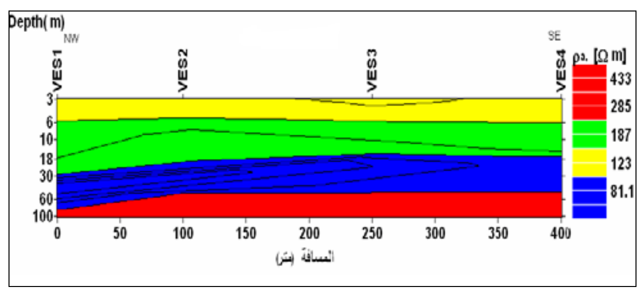

Fig. (14) 1st geoelectrical cross section from NW to SE.

Area (c):

This area has three of vertical electrical soundings (Fig.17, as example). The results showed three geoelectical layers; the first layer consists of dry sandstone and gravel and extends to depth ranging from 5 to 8 meters with resistivity ranges from 103 to 230. Ohm-m; the second layer is dry, or may be composed of sandstone with saline water and has a depth ranges from 5 to 8 meters with resistivity range between 250 and 350 Ohm-m, while the third later is the very dry basement rock with depth ranges from 26 to 93 meters and the resistivity ranges from 553 to 6814 Ohm-m.

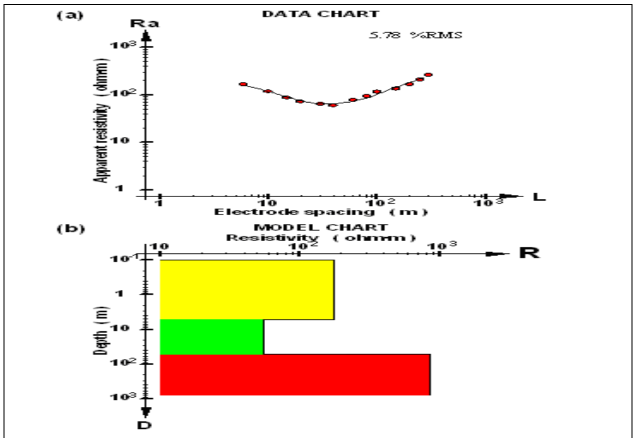

Figure 3. *Inverse modelling for sounding <VES26.dat> - Schlumberger array at "VES26".*

Layer	Depth (m)	Thickness (m)	Resistivity (ohm·m)	Thick/Res (1/ohm)	Thick*Res (ohm·m²)
1	0.000	4.960	176.845	0.028	877.069
2	4.960	47.976	54.699	0.877	2624.264
3	52.936	INFINITY	851.720	-	-
			TOTAL:	0.905	3501.332

Table 3. *Inverse modelling for sounding <VES26.dat> - Schlumberger array at "VES26".*

Fig. (15):VES no. 26 in area (b).

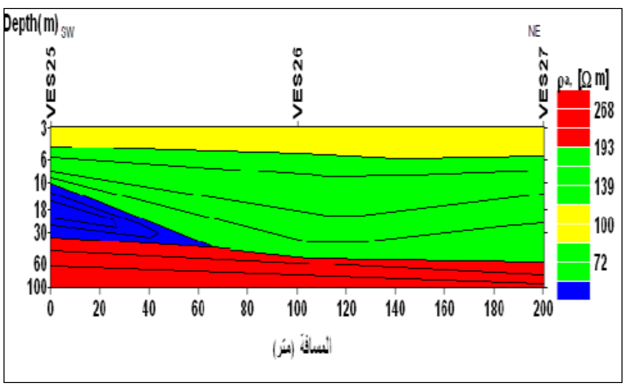

Fig. (16): 5th geoelectrical cross section from NW to SE.

The 7th geoelectrical cross-section (Fig. 18) includes VES No. 28, 29 and 30 and extends from southwest (VES no. 28) to northeast (VES no. 30), perpendicular to the main stream of wadi Malakan with length of 200 m. This section shows that, upper layer composed of wadi deposits with uniform thickness and relatively high resistivity up to more than 100 Ohm-m. Second layer is of variable thickness where it increases towards the northeast and southwest up to the highest thickness under VES no. 30. It is dry and composed of clay of least resistivity (less than 60 Om/m. The 3rd layer represents dry and non-permeable basement rocks with high resistivity up to more than 200 Ohm-m with depth of about 25 meters.

Area (d):

There are three of Vertical Electrical Soundings has been implemented in this area (Fig. 19, as example) and showed the presence of three geoelectrical layers; the first one composed of dry sandstone and gravel and extends to a depth ranging from 7 to 10 meters with resisitivity value ranges between 250 and 350 Ohm-m, second layer consists of sand and silt and the water-bearing layer and extends at depth ranges from 10 to 80 meters with resistivity equals to 39 Ohm-m, while the third one is the very dry and non-permeable basement rocks with depth ranges between 80 and 149 meters and resistivity range from 553 to 6814 Ohm-m.

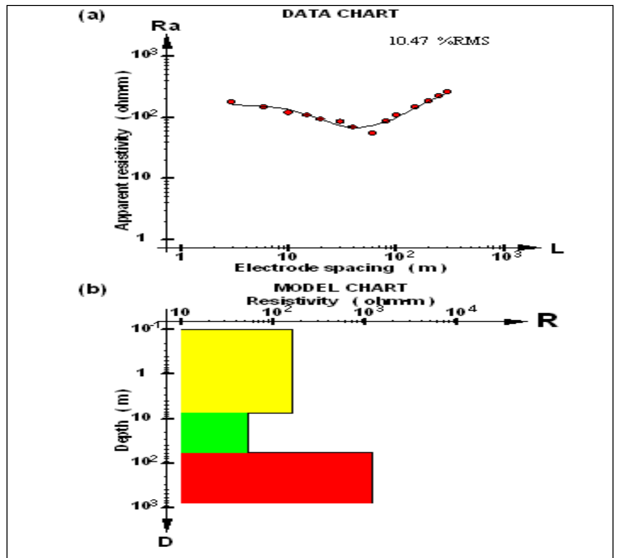

Figure 3. *Inverse modelling for sounding <VES28.dat> - Schlumberger array at "VES28".*

Layer	Depth (m)	Thickness (m)	Resistivity (ohm·m)	Thick/Res (1/ohm)	Thick*Res (ohm·m²)
1	0.000	7.607	158.954	0.048	1209.205
2	7.607	48.374	52.785	0.916	2553.468
3	55.982	INFINITY	1190.107	-	-
			TOTAL:	0.964	3762.673

Table 3. *Inverse modelling for sounding <VES28.dat> - Schlumberger array at "VES28".*

Fig. (17) :VES no. 28 in area (c).

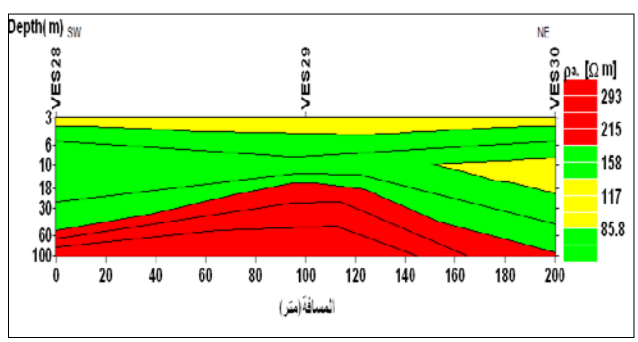

Fig. (18): 7th geoelectrical cross section from NW to SE.

The 8th geoelectrical cross-section (Fig. 20) includes VES No. 19, 20 and 21 is located western part of study area and perpendicular to the main stream of wadi Malakan. This section extends with length of 200 m from southwest (VES No. 19) to northeast (VES no. 21). This section reveals, upper layer of wadi deposits with of uniform thickness and relatively high resistivity up to 100 Ohm-m. Followed by dry layer of variable thickness where it increases to southwest and northeast layer and resistivity less than 45 Ohm-m under VES No. 20. It is noticed that the thickness of this layer less towards the southwest and northeast till disappeared under VES No. 19 and 21. This layer represented by sandy alluvial deposits and believed to be the water bearing layer with high salinity and the thickness about 65 m. The third layer represented by dry and non-permeable basement rocks with high resistivity up to more than 300 Ohm-m and extends to depth of approximately 80 m.

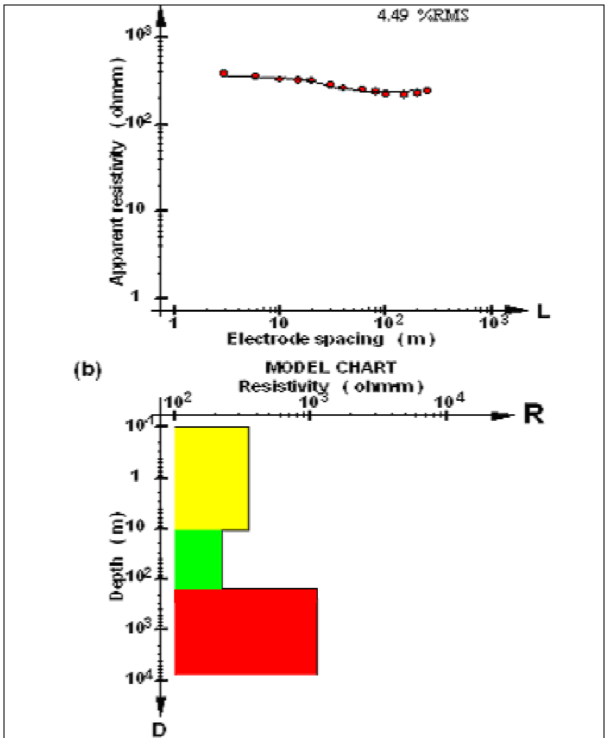

Figure 3. *Inverse modelling for sounding <VES19.dat> - Schlumberger array at "VES19".*

Layer	Depth (m)	Thickness (m)	Resistivity (ohm·m)	Thick/Res (1/ohm)	Thick*Res (ohm·m²)
1	0.000	10.751	351.043	0.031	3774.004
2	10.751	138.065	221.731	1.074	52786.350
3	148.816	INFINITY	1128.926	-	-
			TOTAL:	1.104	56560.353

Table 3. *Inverse modelling for sounding <VES19.dat> - Schlumberger array at "VES19".*

Fig. (19): VES no. 19 in area (D).

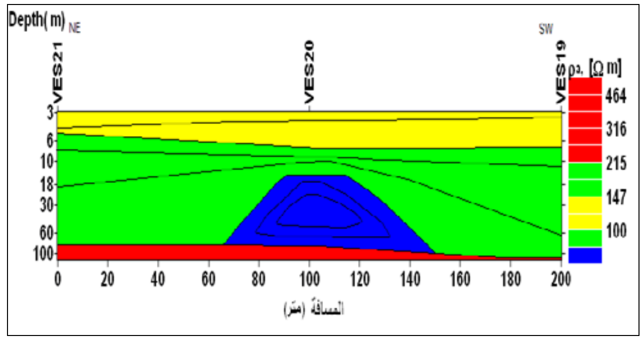

Fig. (20) 8th geoelectrical cross section from NW to SE.

EVALUATION OF GROUNDWATER QUALITY

There are about 13 wells in the study area (Fig.21) in addition to the two of new wells were identified. The producing wells are eight wells and samples of water have been taken from these wells while the rest are non-productive wells.

Based on the chemical analysis of water samples it is noticed that, the main chemical components of water samples were tested for each well of the 8 wells. The parameters that have been evaluated are pH, electrical conductivity, salinity, calcium, magnesium, sodium, chloride, sulphate, carbonates and nitrates (Table 1). It was found that , the detailed descriptions of the groundwater composition is controlled mainly by the location of wells in wadi Malakan based on the study of both the values and properties of water for various wells (Subyani et al. 2004).

PHYSICAL AND CHEMICAL PROPERTIES OF THE GROUNDWATER:

PH values of the groundwater samples ranges from 6.9 to 7.56. These values lie within the permissible limits (6.5 to 8.5) for drinking water in the United States of America. The electrical conductivity for the groundwater increases to the west of study area. Well no. 13/7 (lies to the west of the study area) shows high values with respect to other wells for the major components, especially chloride (2845 ppm), sodium (1380 ppm), sulphate (860 ppm), and calcium (668 ppm) which clarified that the main elements are much higher than the allowable standards for drinking water globally. Chloride values in groundwater samples vary in most wells and ranging from 535 ppm (at the old well no.4) to 1032 ppm (at well 5/10). Dames and Moore, (2001) showed that the concentration of chlorides ranges between 521 mg/L to 1091 mg/L and as expected, the wells which located at the beginning of the study area produce fresh water more than the wells located in the end zone. Sources for the higher chloride content in the study area are due either to the salinity nature for the groundwater in Saudi Arabia or to the increased agricultural activities.

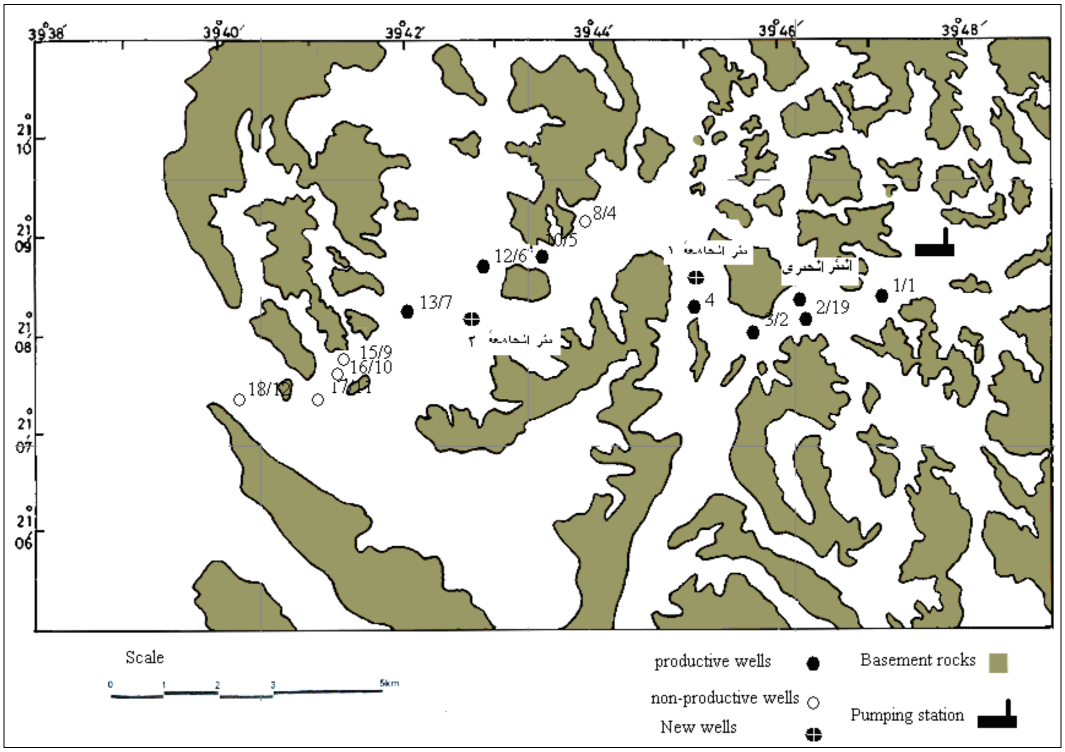

Fig. (21): Groundwater wells in the study area.

Table (1) Main components of chemical analysis for the productive wells in the study area.

Element Well No.	PH	Electrical Conducti. Mmhos/cm	Salinity (PPM)	Chloride (PPM)	Bicarbonate (PPM)	Nitrate (PPM)	Sulphate (PPM)	Calcium (PPM)	Magnisium (PPM)	Sodium (PPM)
1/1	7.2	3576	2750	643.45	96	601.12	544	340	93.6	384.09
2/19	7.38	3225	3440	614.05	108	443.37	494	268	79.2	394.07
3/2	7.43	3070	2320	585.40	108	410.66	468	264	67.2	267.72
Free well	7.56	3150	3285	611.25	108	418.42	481	240	91.2	388.74
4 old	7.38	2660	2000	535.95	108	356.45	341	228	79.2	291.89
10/5	7.45	3685	2830	1032.2	108	282.88	426	324	72	528.49
12/6	7.53	3140	2410	851.7	84	288.77	347	260	48	483.17
13/7	6.9	7730	6400	2845.1	84	368.33	860	668	151.2	1379.93

It is cleared that, the water quality decreases whenever directed to the west and perhaps due to the runoff direction for surface water to the west and therefore with concentration of dissolved salts in the groundwater to reach the top at the western direction from the study area and this corresponds to the previous study conducted by the Dames and Moore, (2001). According to the results of chemical analysis it is concluded that the groundwater in wadi Malakan exceed the permissible limits for drinking while, can be used for irrigation and cultivation of some crops with extreme caution when dealing with the well 13/7 of relatively high salinity.

CONCLUSIONS

Based on the results of both linear structures and magnetic data interpretation, most of the faults take northeast direction which is the dominant trend in the area and northwest of the same faults in the Red Sea. In addition to few faults take the east-west and north-south trend. Modeling of longitudinal transverse and magnetic shows several faults and igneous dykes and determines the depth of basement rocks between the Earth's surface and the depth of 260 meters. the results of the vertical electrical resistivity in the four regions a, b, c, d has shown the presence of four geoelectrical layers; the first one consists of sandstone and gravel and extends to depth ranging from 2 to 4 meters with the resistivity ranges between 103 to 250 Ohm-m, the second layer consists of dry rocks with depth ranges between 4 -10 meters and resistivity ranges from 250 to 350 Ohm-m, the third layer is sandy alluvial layer (water-bearing layer) with depth ranges from 10 to 35 meter and resistivity ranges from 16 to 68. Ohm-m and the fourth later is the basement rock with depth ranging from greater than 22 to more than 149 m with resistivity range between 553 to 6814 Ohm-m.

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