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JOINT INVERSION OF RESISTIVITY (VES) AND TIME DOMAIN ELECTROMAGNETIC (TEM) DATA FOR GROUNDWATER EXPLORATION AT WADI HAGUL, NORTHWESTERN PART OF EASTERN DESERT, EGYPT

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التحويل الدمجى للمقاومة النوعية الكهربائية والكهرومغناطيسية الأرضية فى استكشاف المياه الجوفية فى وادى حجول، شمال غرب الصحراء الشرقية بمصر

الخلاصة: تم استخدام طريقة التحويل الدمجي لنتائج طريقتي المقاومة النوعية الكهربية والكهرومغناطيسية الأرضية في المدي الزمني بطريقة فعالة في البحث و التنقيب عن المياه الجوفيه وتطبيقاتها البيئية فى منطقة وادى حجول، شمال غرب الصحراء الشرقية بمصر. تم قياس ٣٦ جسة كهربية رأسية باستخدام طريقة المقاومة النوعية الكهربية بمسافات تصل إلى ٢٠٠٠ متر بين قطبي التيار الكهربي. كما تم قياس ٣٦ محطة كهرومغناطيسية في المدي الزمني من خلال دائرة كهربية بأبعاد ٥٠ ×٥٠ متراً عند كل محطة لقياس الكهربية، وتمت معايرة و مضاهاة نتائج طريقة التحويل الدمجي مع نتائج حفر بئر في منطقة الدراسة يصل عمقها إلي ٣٥٠ متراً حيث تم اجراء أولي الجسات الكهربية والكهرومغناطيسية بجوار البئر. أظهرت نتائج طريقة التحويل الدمجي أن منطقة الدراسة تحتوي على طبقتين حاملتين للمياه تحت السطحية، الخزان الأول يمثل طبقة خزان المياه العذبة و التي تتميز بقيم مقاومة كهربية حقيقية متوسطه تتراوح ما بين٧ إلى ٣٥ أوم.متر و يتراوح سمكها من١١ إلى ١٠١ متر ويظهر سطحها العلوي عند عمق من ١٥ إلى ٧٠ متراً. أما طبقة الخزان الجوفي الثانية فتتميز بمياه متوسطة الملوحة، تتراوح قيم مقاومتها الكهربية الحقيقية ما بين ١ إلى ٧ أوم.متر كما يبلغ سمكها من ٢٣ - ١٠٣ متر، و تظهر هذه الطبقة عند عمق يتراوح ما بين ٢٥ إلى١٣٠ متراً.

ABSTRACT: *The technique of joint inversion for resistivity and time domain electromagnetic data have been different applications such as groundwater, environments, mineral deposits and archeology. Joint inversion of resistivity/TEM data is an effective approach to characterize groundwater reservoirs. Thirty six stations were measured for DC resistivity (VES) of AB/2 ranging from 500 to 1000 m and 36 TEM stations were measured also beside VES stations of loop sides of 50 x50 m to apply the joint inversion technique. One station was measured beside borehole drilled in study area of depth 350 m for correlation and calibration between the results of joint inversion and data of borehole. The results of joint inversion indicate that the area contain two aquifers, the upper aquifer represents fresh water having moderate resistivity values (7-35 ohm.m) and thickness of 11-101 m at depth ranging from 15-70 m. The second aquifer represents the brackish water having low resistivity values (1-7 ohm.m) and thickness of 23-103 m at depth ranging from 25-130 m.*

1. INTRODUCTION

Correlation, comparison or integration of data from the various electrical and electromagnetic (EM) sounding techniques is a non-trivial task. For example, in the direct current (DC) resistivity method where depth sounding is achieved by varying the electrode separations, the experimental data are shown as apparent resistivity versus electrode separation. In the time-domain or transient electromagnetic (TDEM orTEM) method, where EM energy is applied to the ground by artificial transient pulses and multi-spectral measurements enable information to be obtained from different depths, the data are presented as apparent resistivity versus transient time (usually in ms) or the square-root of time in the Russian literature (Spies 1983). In the magnetotelluric (MT) method employing natural and/or artificial EM field variations on the surface to probe the subsurface, the measured apparent-resistivity data are presented as a function of frequency (or its reciprocal, period) and as apparent resistivity versus the square-root of period in the Russian literature (Spies 1983).

Electric and electromagnetic geophysical methods have been widely used in engineering, mining and groundwater investigations because of good correlation between electrical properties of the rocks and fluid content of geological formations (Flathe, 1955; Zohdy, 1969; Fitterman and Stewart, 1986; McNeill, 1990). Among the various geophysical methods, the direct-current (DC) or resistivity method is probably the most popular in groundwater studies due to the simplicity of the technique, easy interpretation of the data and rugged nature of the associated instrumentation. The technique is widely used in soft and hard rock areas (e.g. Van Overmeeren, 1989; Urish and Frohlich, 1990; Ebraheem et al., 1997). The transient electromagnetic (TEM) method is relatively new. It has been developed more intensively since the mid-1980 and has been commonly used in environmental and hydrogeological investigation (Meju, 2005 and Goldman et al., 1994). It is well known that DC (direct current) soundings are quite sensitive to resistive layers and structures imbedded in section as well as sensitivity to conductive layers. The TEM (transient electromagnetic method) shows a complementary behavior because it is very sensitive to conductive layers and insensitive to resistive ones (Barsukov et al., 2004).The area under investigation lies between latitudes 29° 36′ 30″& 29° 50′ 30″N and longitudes 32° 13′ 20″& 32° 23′ 40″E, with a total area of 270 km^2, representing the northwestern area of the Gulf of Suez, between Ataqa mountain and Northern El Galala plateau (Fig. 1).

2. GEOLOGY OF THE AREA

The stratigraphic column of the area under investigation has exposed on the surface and represented by two locations, the first is Okheider Mountain at the western side of the region and completed by the faulted parts below, where the layers of these faulted parts are dipping to the eastern direction, until covered by recent alluvium at the coastal plain. The second location is Ataqa mountain, where the old rocks at the low southern margins of Ataqa mountain and their layers are dipping at this part to the south and southwest. Also the old rocks are exposed on the surface below the series of the western mountains, which include Kaheilia and Um Zieta mountains and the layers dipping at this part toward the eastern and southeastern directions. Figure (2) shows the geologic map of the study area. The surface geology was discussed by Abdallah and Abd El-Hady (1966) and Abdallah, (1993).

The subsurface stratigraphy in the study area has been described through borehole which drilled by geological survey of Egypt, 1999 (Fig.3). The borehole description indicates that the Quaternary deposits represented by wadi deposits, sand and gravel with thickness of about 4 m. These Quaternary deposits overlay Upper Miocene deposits which represent by sandstone deposits , this sandstone is saturated by fresh water (1200 ppm) and has thickness of 34 m. Middle Miocene is represented by sandstone and limestone of thickness about 119.1 m , the upper part of these deposits contain brackish water (2500 ppm). Lower Miocene is represented by Limestone and clayey sandstone of thickness 109.1m these deposits overlay the Oligocene deposits which have been represented by clayey sandstone of thickness about 33.6 m. Upper Eocene deposits have been represented by clayey limestone of thickness about 49.6 m which overlay the Middle Eocene deposits at the base of borehole.

3. JOINT INVERSION DATA INTERPRETATION

The joint inversion of DC resistivity (schulmberger configuration) and time domain electromagnetic (TEM) was carried out on 36 stations which measured DC resistivity and TEM (Fig. 4). One station No.53 was measured beside borehole No.1 for correlation between VES data and borehole data (Fig. 5). The interpretation of VES data was carried out firstly to use the results as an initial model for joint inversion program (Fig. 6). After correction of DC resistivity data for static shift the program for joint inversion (Meju's code, DCEMINT, Version 1995).

3.1. Joint inversion cross-sections:

The results of quantitative interpretation for joint inversion of DC resistivity and TEM data are used to construct five sections represent the variation of layers according to their resistivity values. The joint sections A-A`, B-B`, D-D`, E-E` and F-F`, Figs. (7, 8, 9, 10 and 11) indicate that the subsurface section of the study area consists of eight layers representing different geological succession. The first layer is corresponding to Wadi deposits, second layer corresponds to sandstone, third layer is a clay of Quaternary deposits, fourth layer represents the shallow aquifer of fresh water, the fifth layer represents the lower aquifer of brackish water, sixth layer is sandstone and limestone of high resistivity value, seventh layer is clayey sandstone and limestone of low resistivity values and eighth layer is the limestone of middle Eocene which exhibits high resistivity values.

3.2. Depth map for upper surface of shallow aquifer

The depth map for the top surface of the first aquifer (Fig. 12) indicates that the central part of the study area reflects deep depths about 60 m to 65 m, but the northern and southern parts reveal shallow depths about 15 to 20m.

3.3. Depth map for lower surface of shallow aquifer or upper surface of deep aquifer:

This map shows that the central parts of the study area reveal deep depths reached up to 160m and shallow depths (25 to 30m) are shown at the northern and southeastern parts of the study area (Fig. 13).

3.4. Depth map for lower surface of deep aquifer:

The depth map for the lower surface of deep aquifer (Fig. 14) reveals that the central part of the study area is deeper and the shallow depths are recognized at the northern, western and eastern parts of the study area.

3.5. Isopach map of the shallow aquifer:

The isopach map of the first aquifer (Fig. 15) exhibits large thickness at the southern part, particularly at the southwestern part with a thickness reaches to 120 m, but the northern part is characterized by moderate to small thickness ranged between 35 to 15 m. This map indicates the distribution of sand and sandstone saturated with fresh groundwater thickness values of Upper Miocene sediments, which represents the first aquifer of the study area.

3.6. Isopach map of the deep aquifer

The isopach map of the second aquifer (Fig. 16) shows considerable thickness values at the central and western parts of the study area of about 80m to 125 m, but the southwestern and northeastern part are characterized by moderate thickness values of about 40 to 23 m.

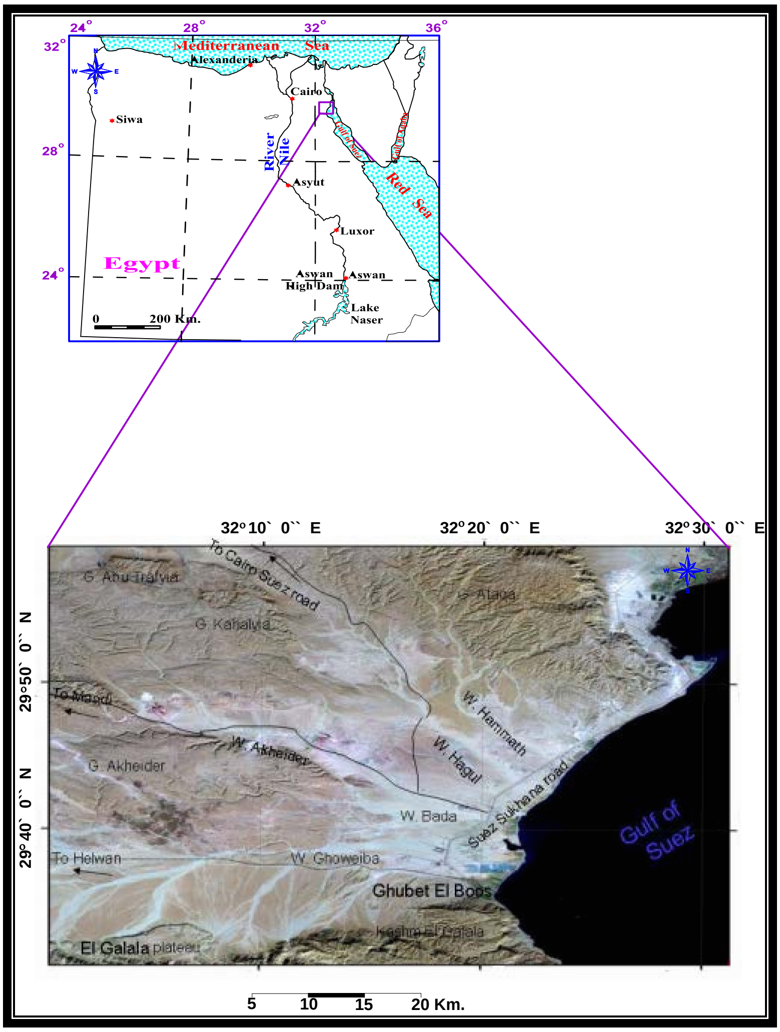

Fig. (1): Location map of the study area.

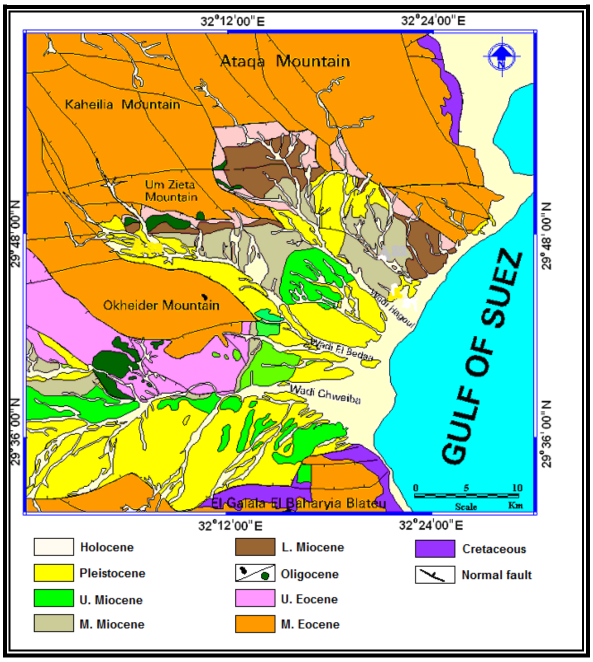

Fig. (2): Geological map of the northwestern part of the Gulf of Suez (modified after the Egyptian Geological Survey, 1999).

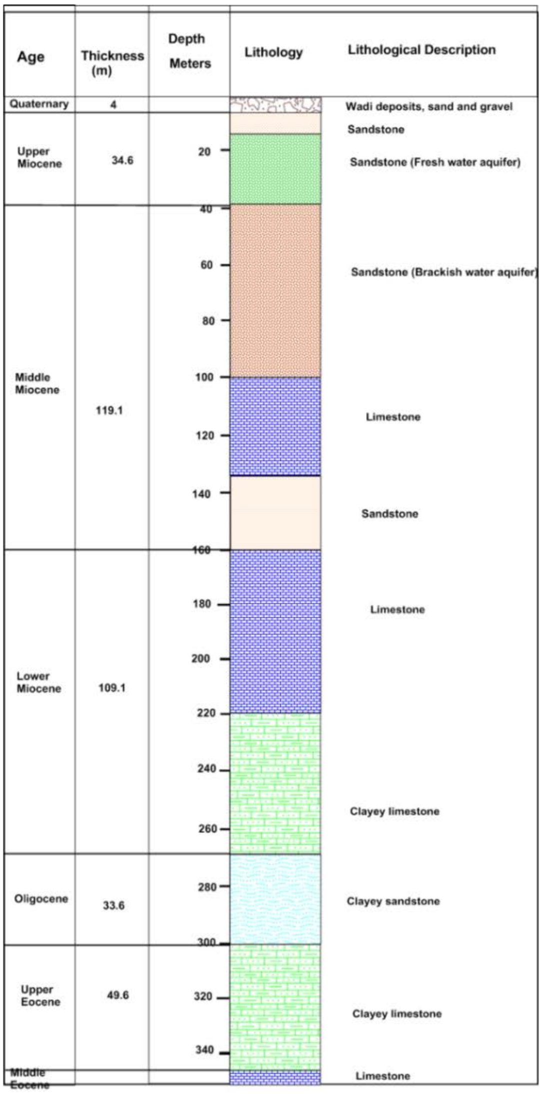

Fig. (3): Description of borehole No.1 (EGSMA, 1999).

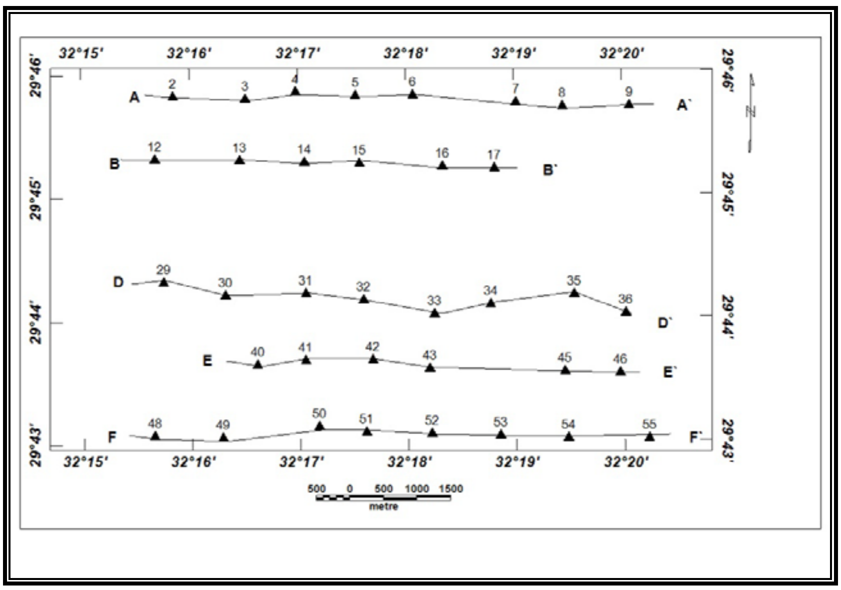

Fig. (4): Location map of VES and TEM stations at the study area.

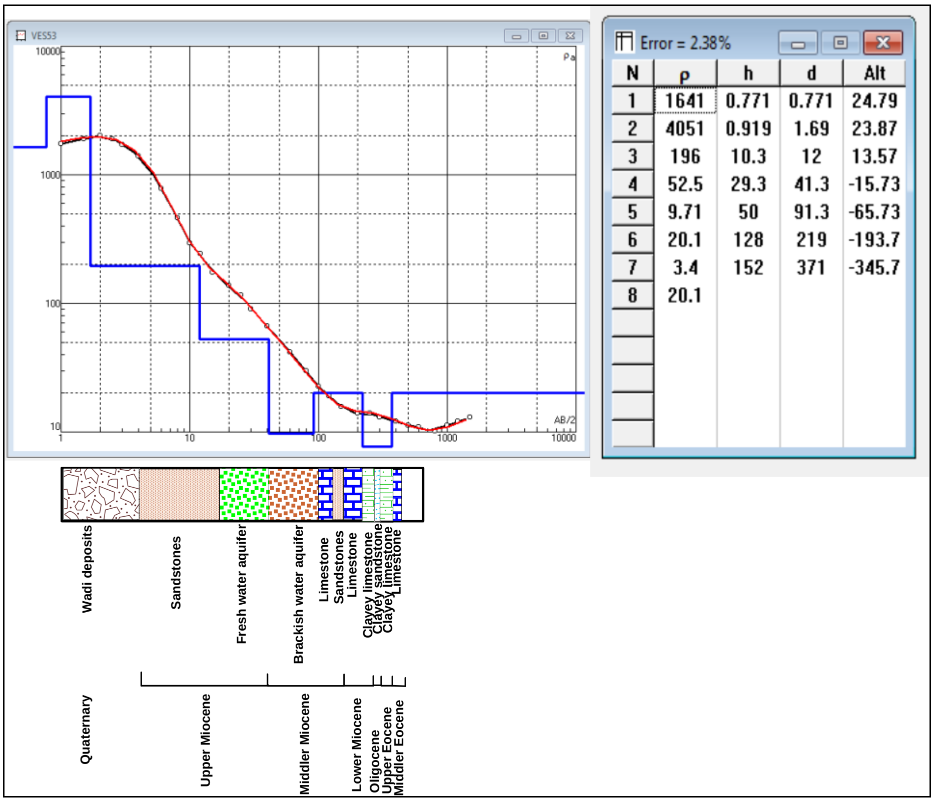

Fig. (5): Interpretation of VES station No.53 calibrated with borehole1 using IPI2WIN Program.

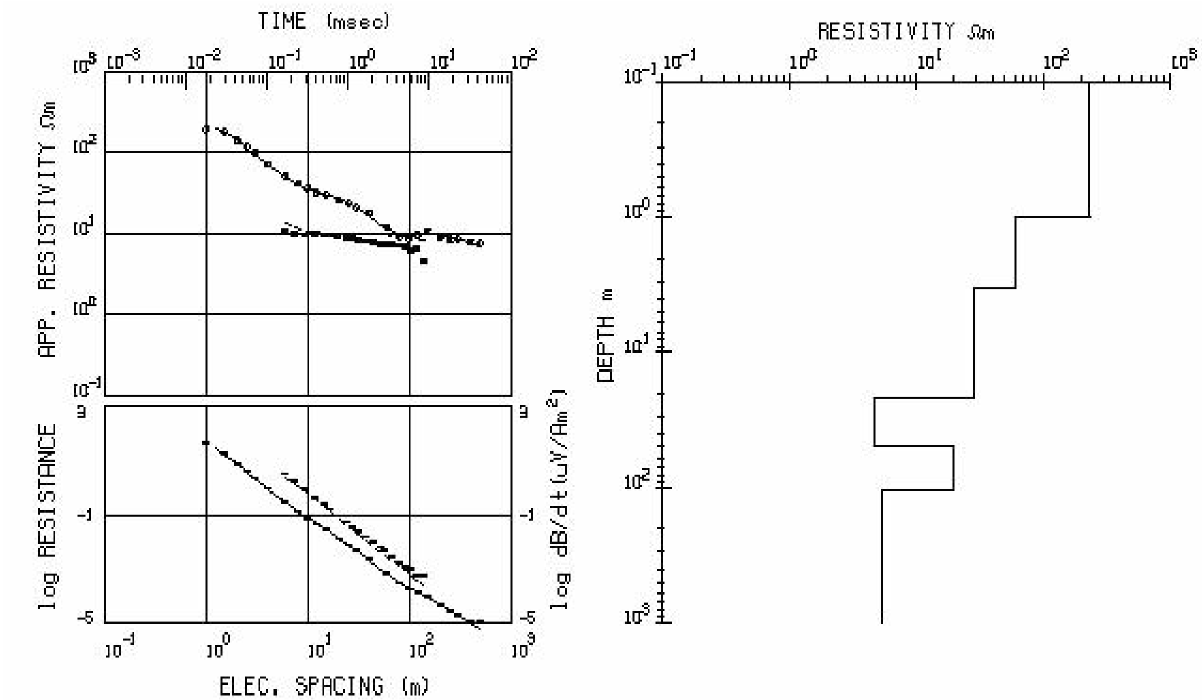

Fig. (6): Joint inversion interpretation of VES and TEM for station No. 31 using (Meju's code, DCEMINT, Version 1995).

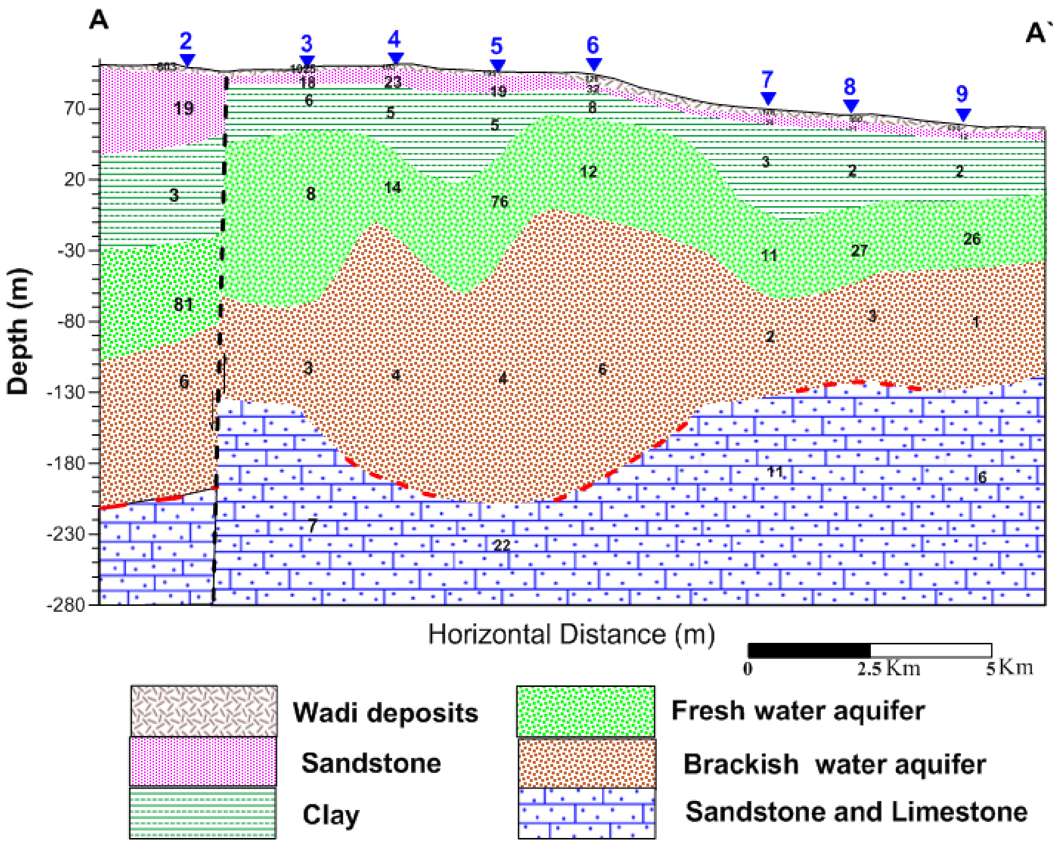

Fig. (7): Joint section A-A`.

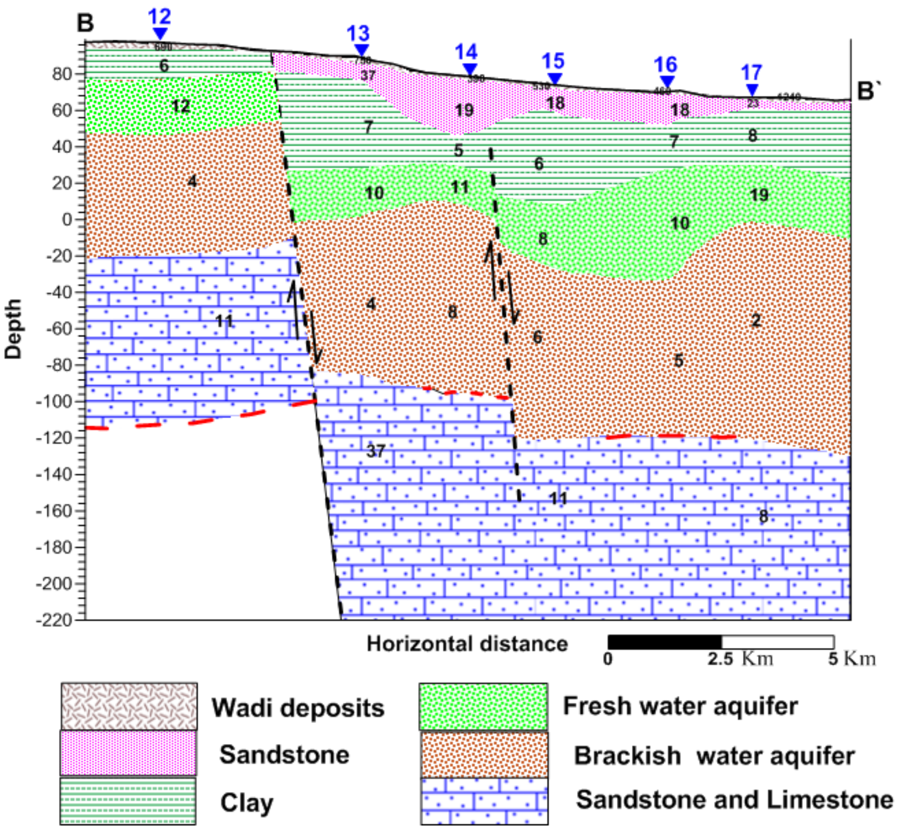

Fig. (8): Joint section B-B`.

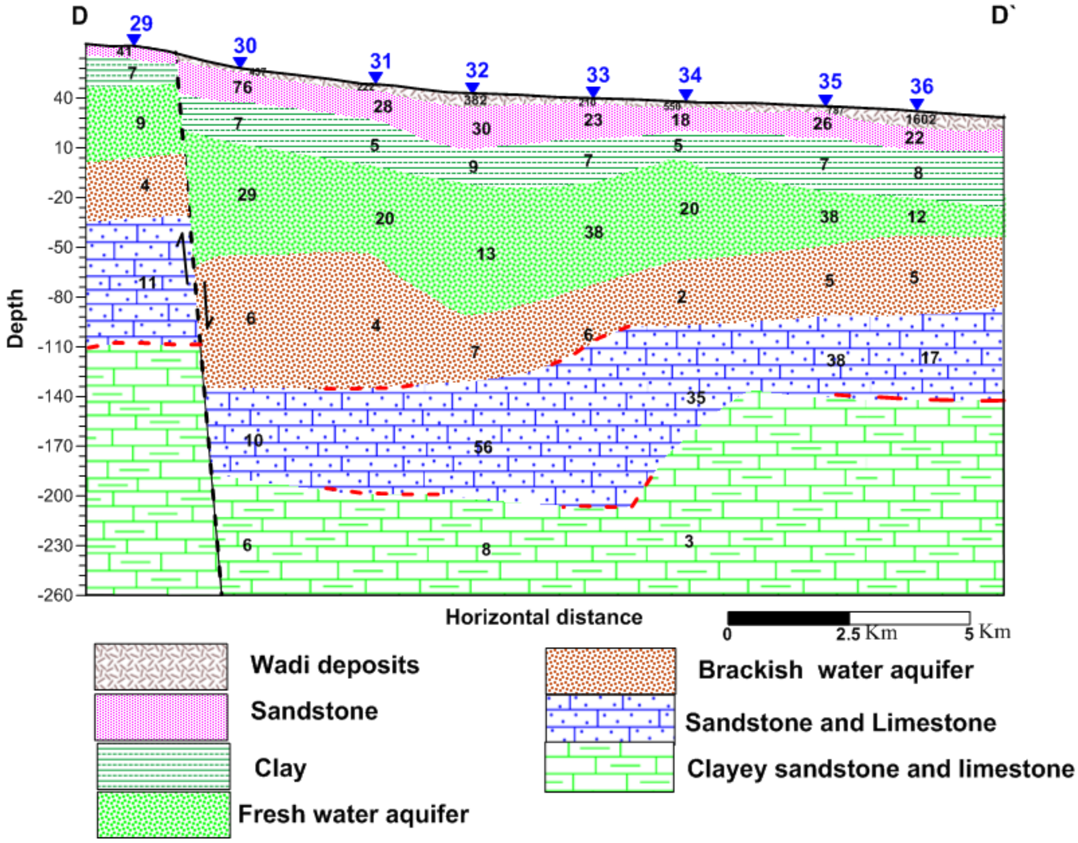

Fig. (9): Joint section D-D`.

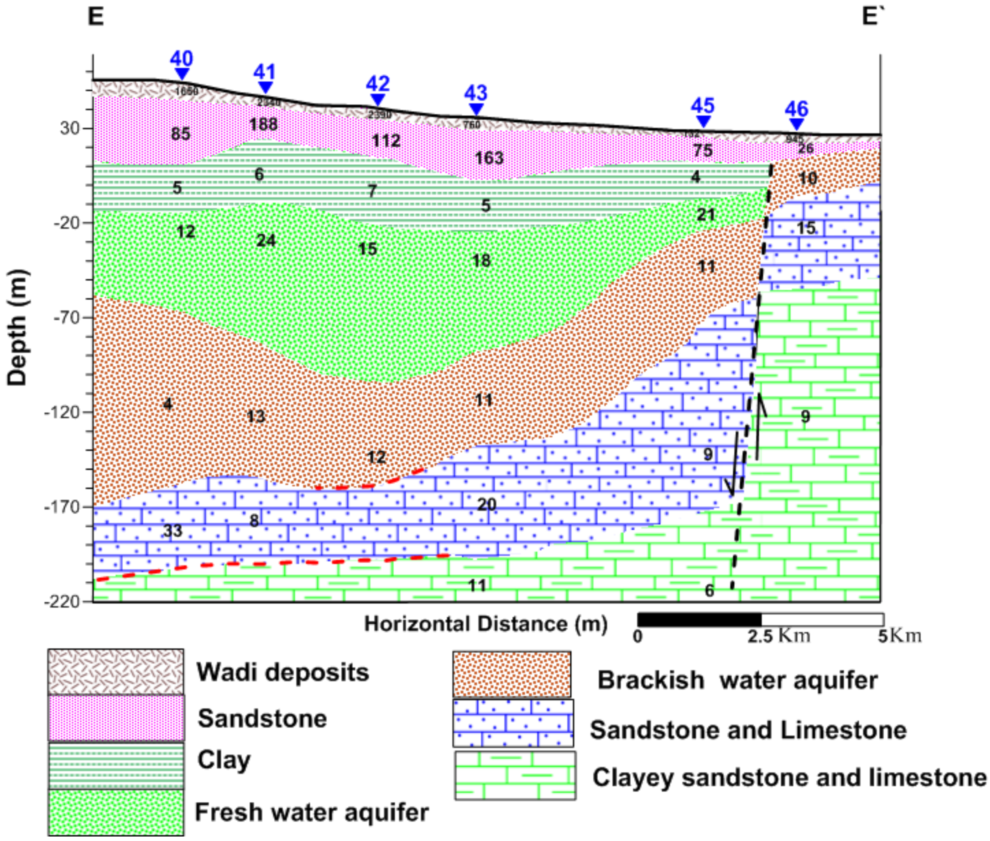

Fig. (10): Joint section E-E`.

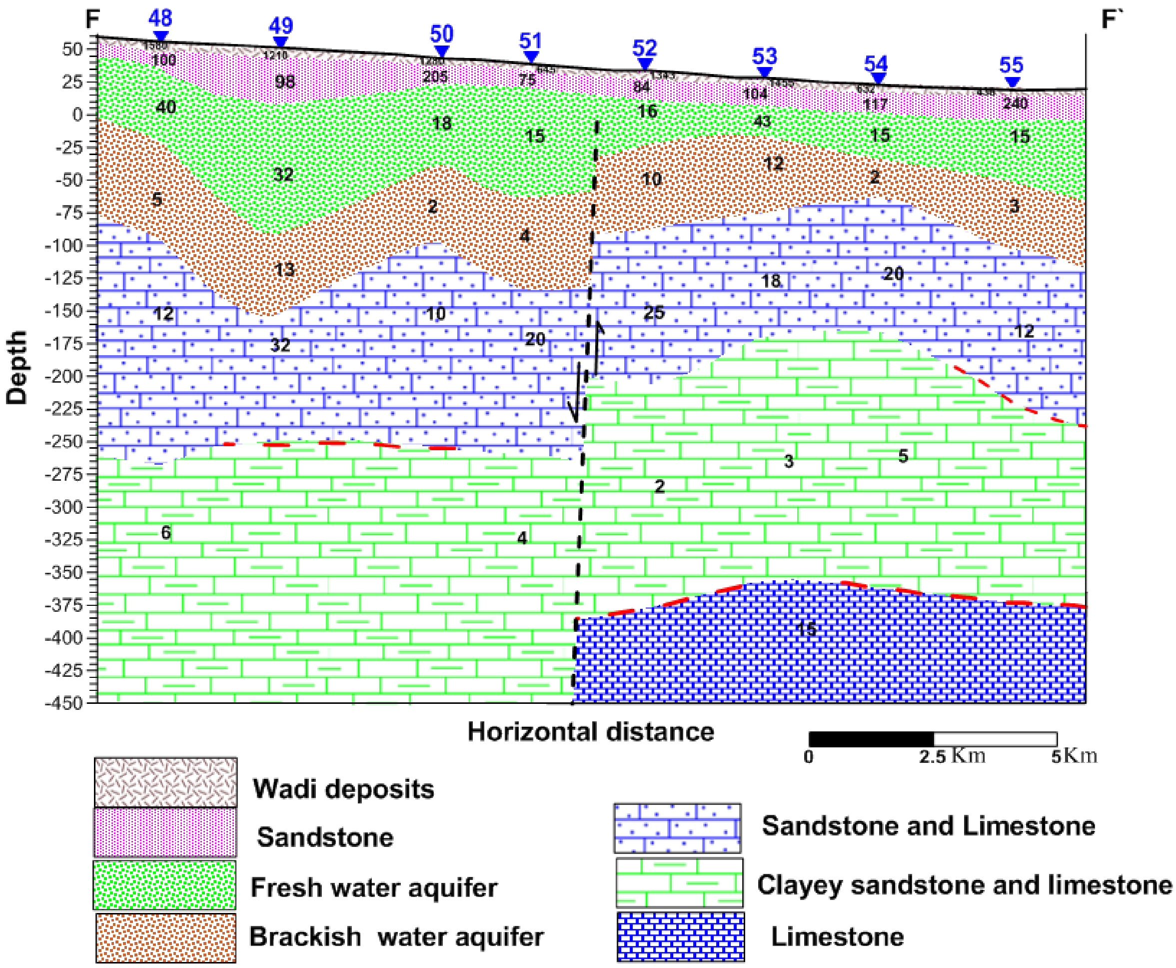

Fig. (11): Joint section F-F `.

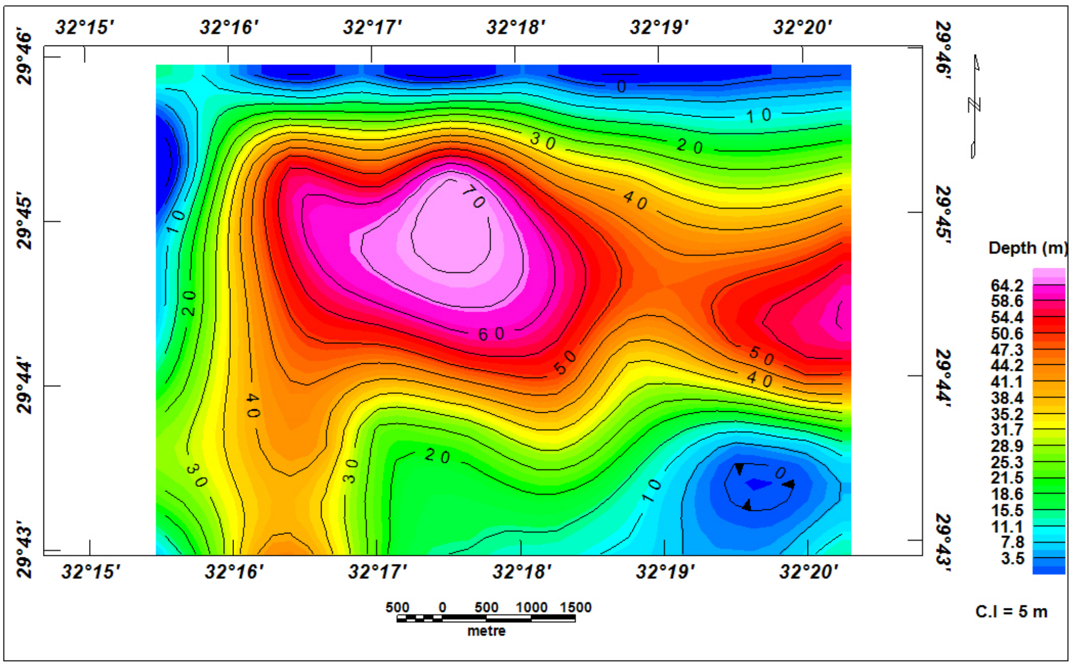

Fig. (12): Depth map of the upper surface for shallow aquifer from joint interpretation.

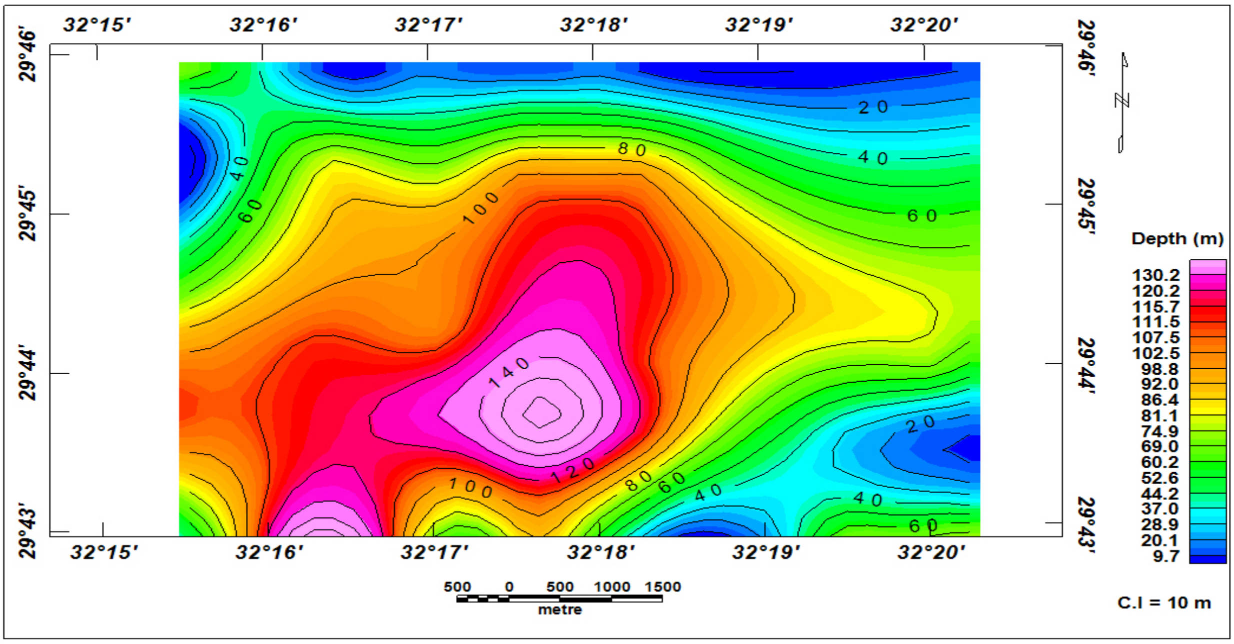

Fig. (13): Depth map of the lower surface for shallow aquifer or upper surface of deep aquifer from joint interpretation.

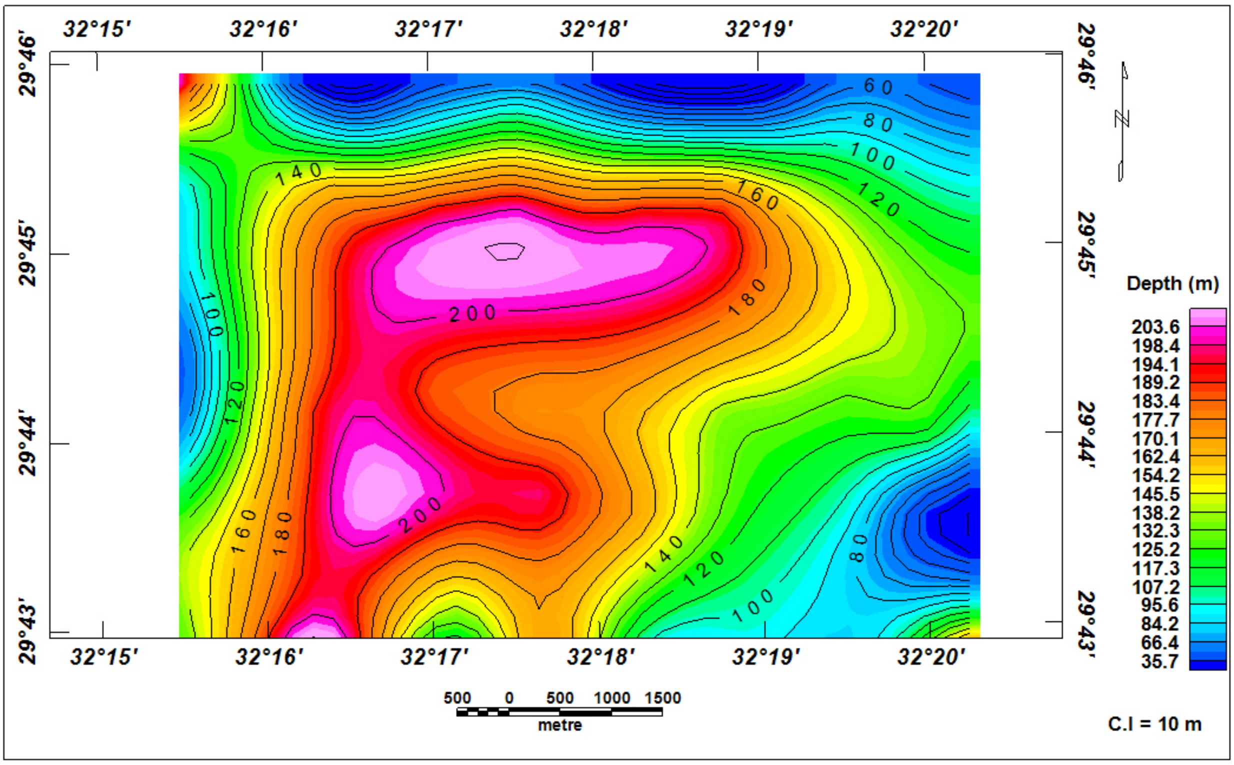

Fig. (14): Depth map of the lower surface for deep aquifer from joint interpretation.

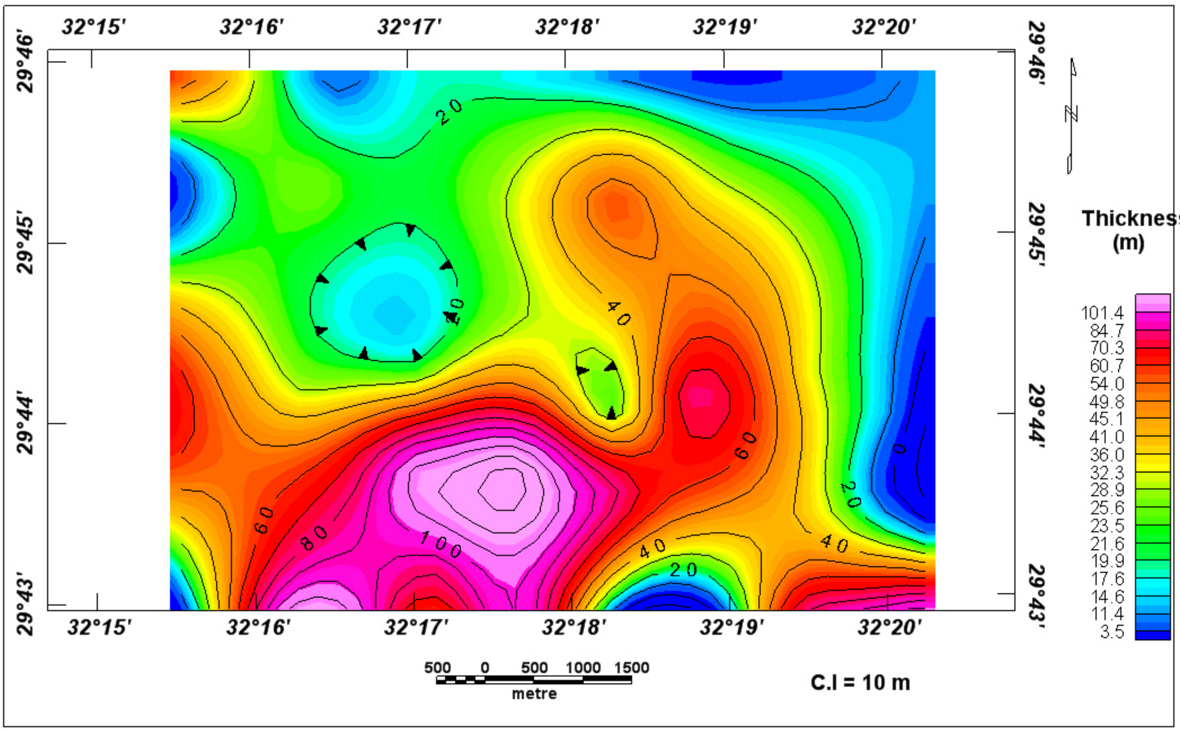

Fig. (15): Isopach map of the shallow aquifer from joint interpretation.

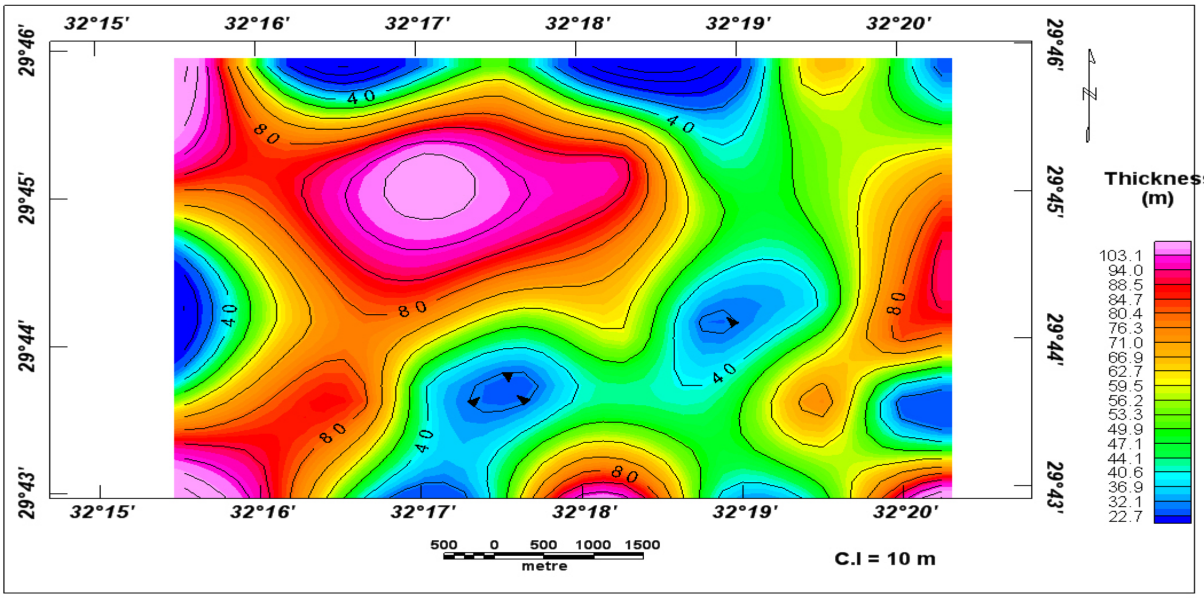

Fig. (16): Isopach map of the deep aquifer from joint interpretation.

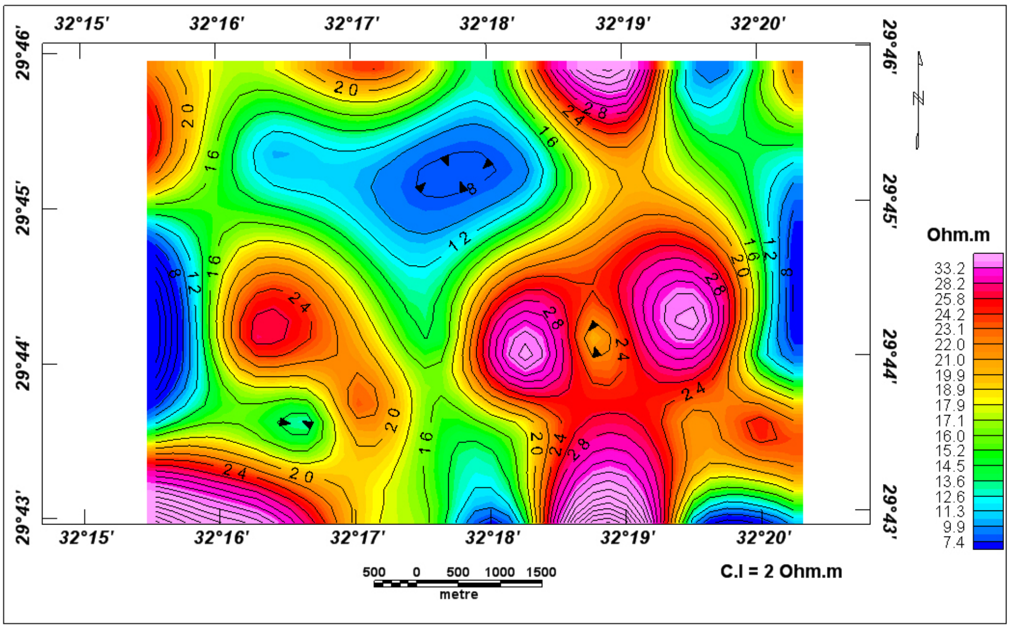

Fig. (17): Isoresistivity map of the shallow aquifer from joint interpretation.

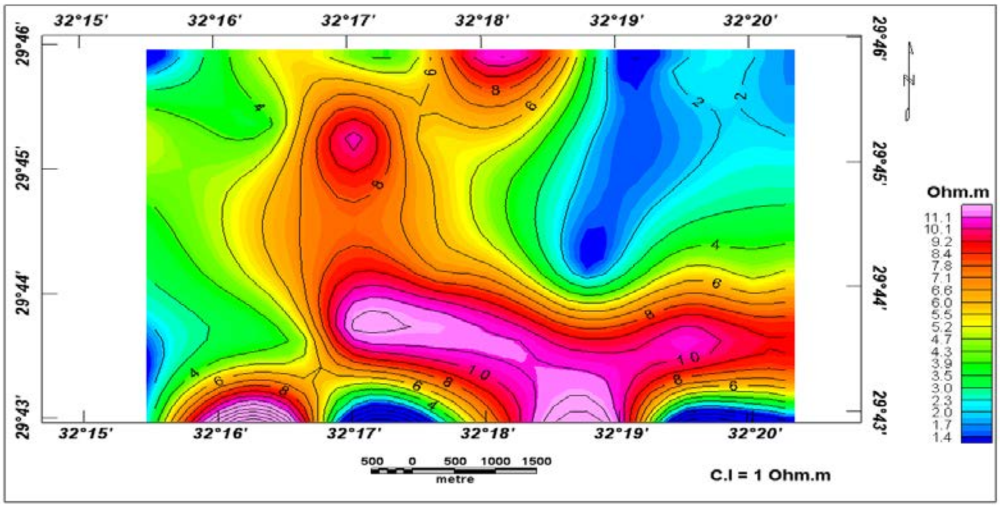

Fig. (18): Isoresistivity map of the deep aquifer from joint interpretation.

This map illustrates the thickness values of the sandstone intercalated with clay (clayey sandstone) of Upper Miocene deposits which represents the second aquifer in the study area.

3.7. Isoresistivity map of the shallow aquifer:

The shallow aquifer exhibit low to moderate resistivity values ranged from 7 to 35 ohm.m (Fig. 17).

3.8. Isoresistivity map of the deep aquifer:

The deep aquifer reveals very low resistivity values ranging from 1 to 11 ohm.m (Fig. 18).

4. CONCLUSION

This work is resistivity/TEM joint inversion, as an effective approach to characterize groundwater aquifers and structural elements which dissect the study area. The results obtained from joint inversion in the vicinity of a well are compatible with the results from the geological log. The study area contains two aquifer of different thickness, the first is the upper aquifer of fresh water which reflects moderate resistivity values ranging from 7-35 ohm.m and thickness of 11-101 m at depth ranging from 15-70 m. The second aquifer is the lower aquifer which represents the brackish water aquifer of low resistivity values ranging from 1 to 7 ohm.m and thickness ranging from 23-103 m at depth ranging from 25-130 m. The area dissects by fault elements which dissect all sections.

5. REFERENCES

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