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# Geophysical investigation to reveal the groundwater condition at new Borg El-Arab industrial city, Egypt



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## KEYWORDS

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**Abstract** New Borg El-Arab City, 60 km to the southwest of Alexandria City, is one of new industrial cities planned by the Egyptian Government through its program to transfer the population from the condensed Nile Delta to other places in Egypt. Because such a city includes airport, huge buildings, factories, and worker settlements, a careful geophysical study is planned to reveal the groundwater condition. This will help in defining the places of wells that are supposed to be drilled. Therefore more industrial and agricultural activities will be flourished.

The present study embraces Vertical Electrical Soundings (VES'es) and Time Domain Electromagnetic sounding (TEM) to investigate the study area. The study aims to delineate the main subsurface conditions from the viewpoint of groundwater location, depth and water quality. Analysis and interpretation of the obtained results reveal that the subsurface consists of five geoelectrical layers with a gentle general slope toward the Mediterranean Sea. The third and the fourth layers in the succession are suggested to be the two water bearing formations of which the third layer is saturated with fresh water overlying saline water at the bottom of the fourth one. It is worth mentioning that the fresh water depth varies between 50 and 354 m under the ground surface. The thickness of the fresh water aquifer varies from 9.5 to 66 m; and the saline water depth varies between 116 and 384 m below the ground surface, the thickness of saline water aquifer differs from 34 to 90.5 m.

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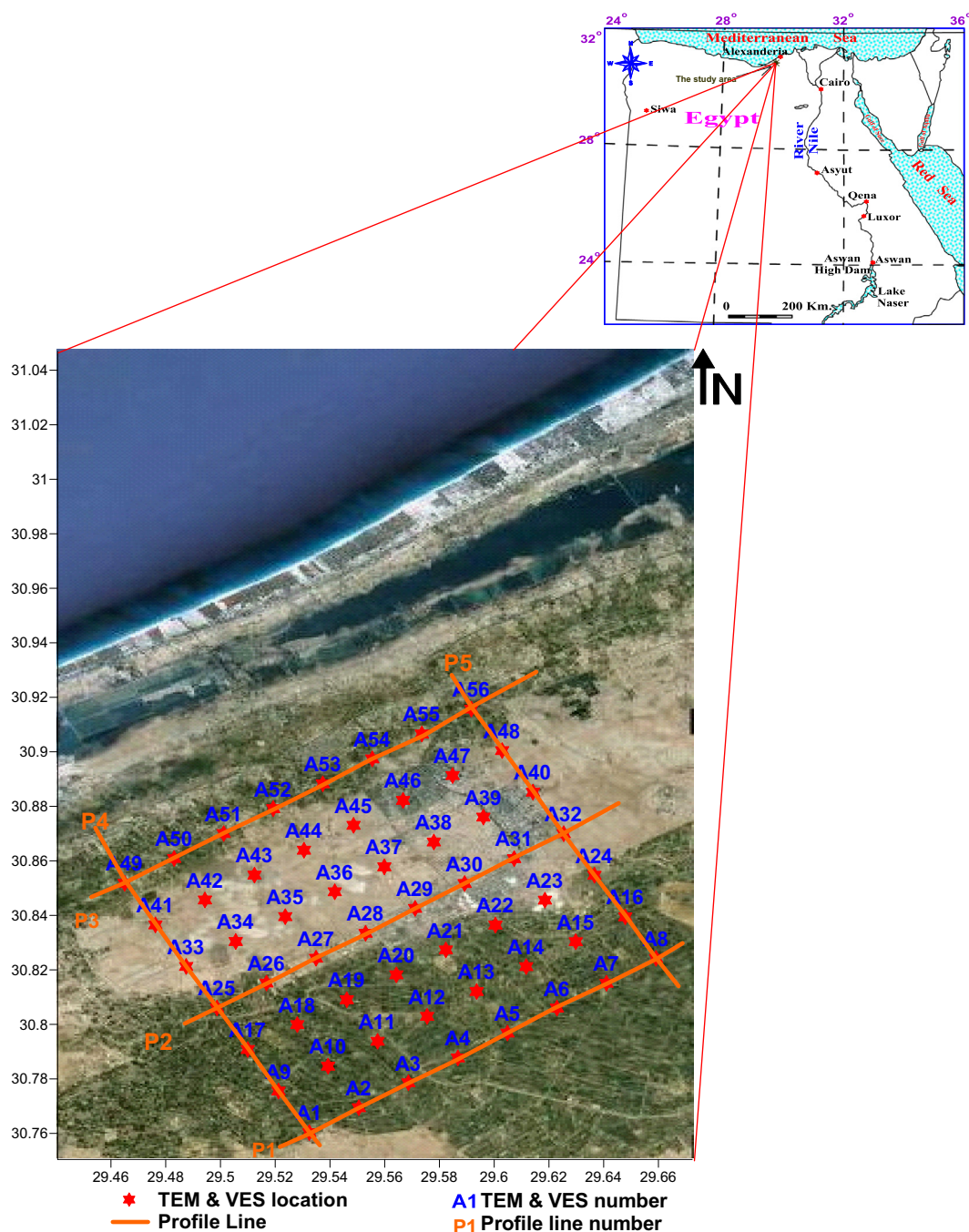
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## 1. Introduction

The new Borg El-Arab City is one of the new industrial and agricultural cities. It covers an area of about 90 km<sup>2</sup>. It lies between latitudes 30.75043221 and 31.04684093 N and longitudes 29.44052705 and 29.6723497 E (Fig. 1). The city, as industrial and agriculture one, needs a careful study to provide new sources of water. It is also required to delineate



**Fig. 1** Location map of both VES's station and TEM's stations with cross sections along the study area.

the groundwater and its ability to be used and extracted to help in domestic, industrial and agricultural activities.

In this regard, the present geophysical survey at the suggested location of new Borg El-Arab City, utilized Vertical Electrical Soundings VES'es and Time domain electromagnetic surveys. It will assist in detecting the best sites to drill water wells, most excellent places to cover with vegetation, and is capable of furnishing useful information of groundwater characteristics in the area.

The integrated interpretation of these techniques classified the subsurface succession into five geoelectrical layers. The first layer composes weathered sandy clay. The second layer

consists of sand belonging to "Oligocene age". The third layer composes sand saturated with fresh water. The fourth layer consists of sand saturated with saline water. The fifth layer of the study area composes limestone belong to "Miocene" age.

## 2. Geological setting

According to El shaazly (1964), the geological setting of the study area is related to the delta formation, this formation is a landform that is formed at the mouth of a river, where the river flows into a sea, this formation consists of (from top to

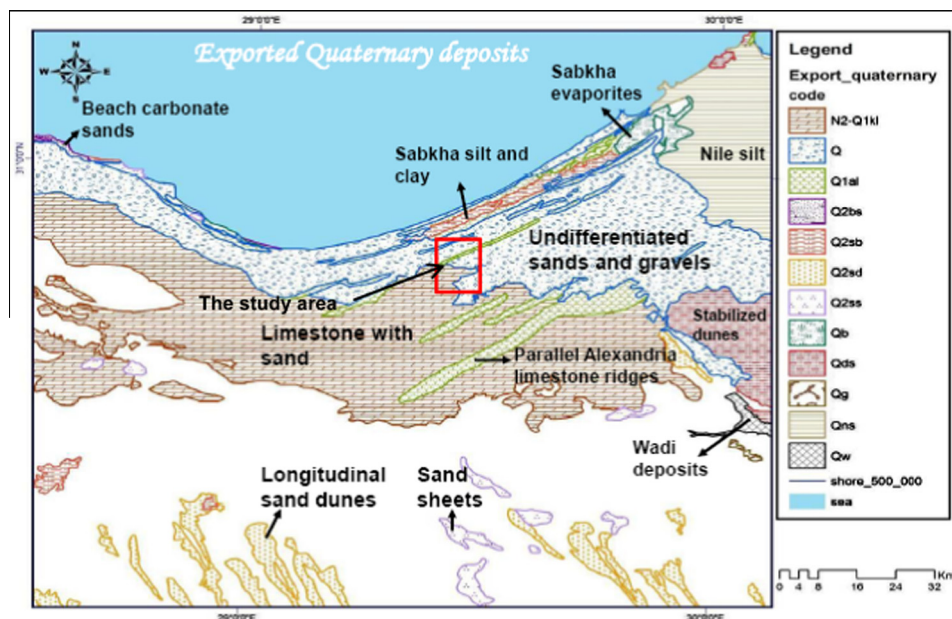


Fig. 2 Geological map of the study area in the west of Bourg El-Arab (after GNBCC, 2012).

bottom) Quaternary deposits (scattered), Oligocene (Sand), Beniolitic Clay, and Middle Miocene as Limestone. Fig. 2 shows the geology map of the study area.

Abd ElMawla, 2010 shows the geomorphologic units of the west of Alexandria found in Fig. 3.

### 3. Data acquisition and survey

The most useful type of sounding array “Schlumberger” has been used in this study. This array is very convenient for

resistivity-depth sounding, because of its low-cost, and is time-saving. It is also considered a real tool of groundwater exploration that gives detailed information about subsurface geology. Moreover, it is more suitable to hydrogeological survey of sedimentary basin.

The Syscal/R2 acquisition system with AB/2 1000 m was used in the measuring of (56) VES'es distributed over the studied area to reveal the subsurface geoelectrical layers in the study area (Fig. 1).

SIROTEM MK3 instrument was used in the TEM survey. It detects underground conducting materials by transmitting

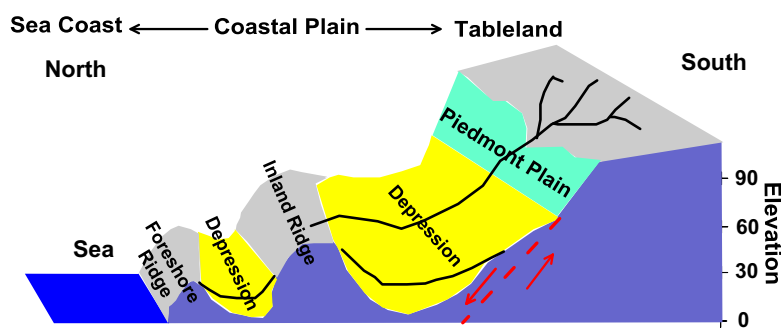


Fig. 3 Geomorphologic units of west of Alexandria (Abd Elmawla, 2010).

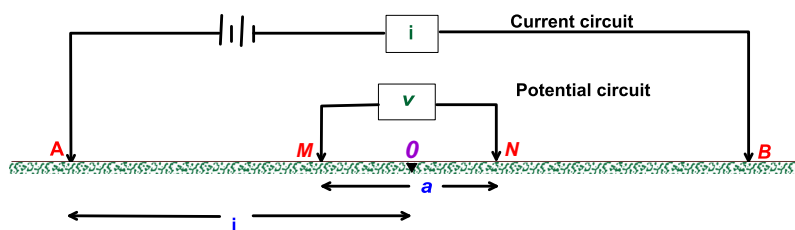
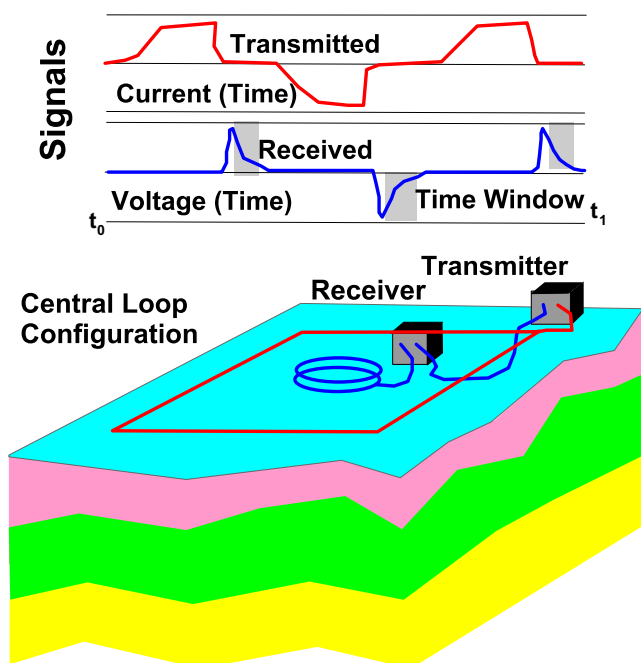


Fig. 4 (a) Current lines and equip-potentials for a pair of current electrodes A and B on a homogeneous half-sp e. ac. (b) Schlumberger electrode arrangement used in DC resistivity surveying.



**Fig. 5** TEM system in central-loop configuration and the transmitted and received TEM waveforms.

electrical pulses along loops of cable laid out on the surface. It is unique in having the transmitter and receiver in a single unit. The major components of SIROTEM MK3 are contained in a robust, portable console unit. In this study, a 50 m × 50 m square loop was used with a very short period of time as 0.23–3.7-m s (see Fig. 4).

TEM soundings were made of a receiver and transmitter unit attached to a receiver and transmitter loop. The transmitter passes a constant current through the loop, which produces

a primary magnetic field (Fig. 5). The current is quickly turned off, thereby interrupting the primary magnetic field. To satisfy Faraday's law, currents are induced in the ground, which instantaneously maintain the primary magnetic field. This current system, which flows in closed paths below the transmitter loop, produces a secondary magnetic field. Changes of the secondary magnetic field with time induce a voltage in the receiver, because the magnitude and distribution of the current intensity depend upon the resistivity of the ground, the voltage gives information about the resistivity of the ground. The locus of the maximum amplitude of the induced currents diffuses downward and outward with time, thereby giving information about deeper regions as time increases (Nabighian, 1979). The signal recorded by the receiver is called a transient.

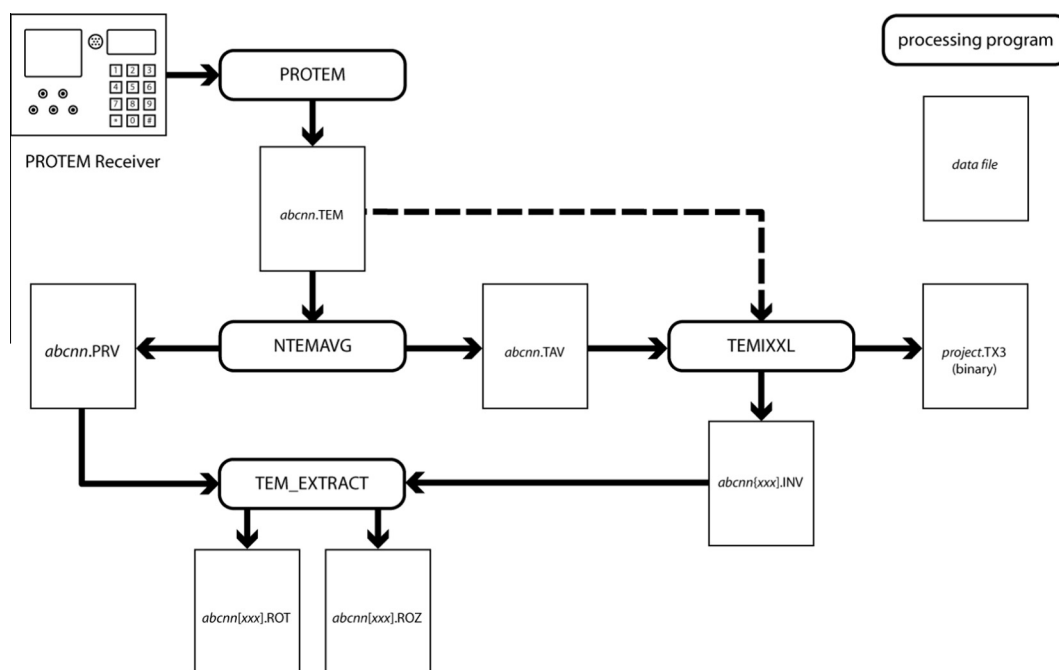
#### 4. Data interpretation

The attendance work of the Vertical Electrical Sounding data of the new Borg El-Arab City has been carried out with the endeavor of illustrating the general hydrogeological picture. Also, it demarcates the resistivity change behavior within the probed formations. In doing so, analysis of the obtained measurement results has been complemented through construction and description.

The interpretation of these electrical soundings has been carried out by using Zohdy (1989) and Resist (1990) software. The output recounted the number of layers, their thicknesses and each layer's resistivities.

Exemplars of the quantitative interpretation for some of sounding curves of the study area using Resist's software are represented in Fig. 7.

The interpretation of the electromagnetic sounding has been automatically produced by using "TEMIX XL's software 1996". The production described the number of layers, their thicknesses and each layer's resistivities, as a reverse



**Fig. 6** Data processing programs, files, and flow. Solid arrows indicate processing flow. Dashed arrow indicates an alternate path.

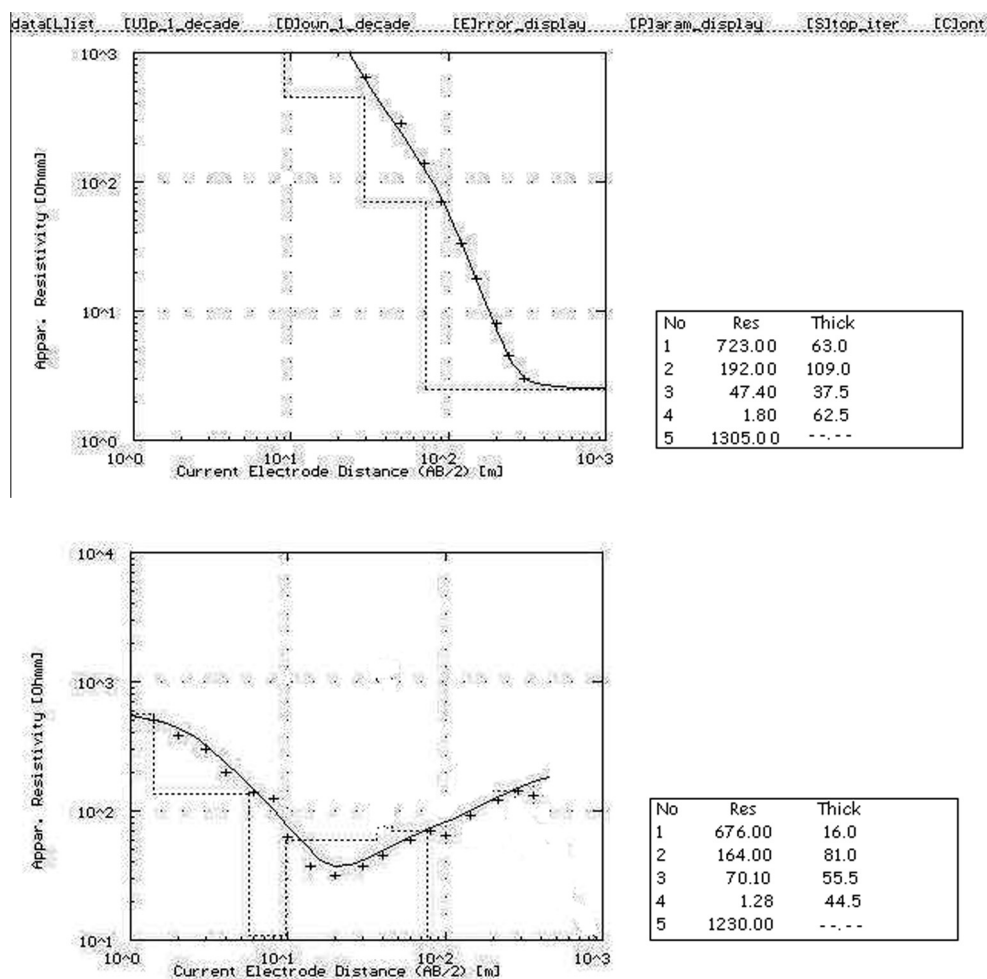


Fig. 7 Example for the interpretation of Vertical Electrical Sounding No. 11 and No. 23 by Resist's software.

of its conductivities. Exemplars of the quantitative interpretation for some of sounding curves of the study area using TEMIX XL's software are represented in Fig. 8.

The EM data in the Geonics PROTEM receiver are downloaded to a PC using program PROTEM, which is supplied by Geonics. Typically data from one sounding location are downloaded into a single raw-data file. The file format is referred to as Geonics TEM File Format (GTFF). Following downloading, selected data records from the raw data file are averaged using program NTEM AVG. The averaged data files are also in GTFF format. In addition to the averaged data file, a file containing a summary of the averaging process is saved.

Both the raw and averaged data files can be read into TEM-IXXL. TEMIXXL stores a copy of the data, the model, and the calculated response of the model in a proprietary, binary database file. The database can hold a large number of soundings, so one database is usually enough for an entire survey. Sometimes it is helpful to retain several alternative models for a given data set. These are stored as separate soundings in the TEMIXXL database. Typically these alternative models have the original sounding name with up to 3 characters added at the end. For example, a sounding called ABC01, might have variants ABC01L4 and ABC01L5 to indicate models with four and five layers, respectively. There are no restrictions on the extra characters added to the sounding name other than the

total number of characters in the sounding name that cannot exceed 8. The results of the inversion are reported in an inversion output file. Program TEM\_EXTRACT is used to extract apparent-resistivity-time and interpreted-resistivity-depth files for plotting. Fig. 6 shows the EM Data analysis procedure.

Both software of the electrical and electromagnetic sounding depend on automatic curve-matching operation, also known as "inversion". This option allows the computer to try thousands of potential solutions and converge on one that best fits the data – the program can then quantitatively assess other solutions that fit the data almost as well as the optimum best-fit solution. These other solutions give an idea of the uncertainty in the thickness and resistivity of each layer. Geophysicists call this uncertainty "equivalence".

## 5. Results

### 5.1. Geoelectrical cross-sections

The final interpretation of VES and TEM results may indicate the shallow subsurface sequence of the area in the form of the geoelectric layers with different thicknesses and resistivities. These results have been used in depicting some valuable forms of geoelectrical cross-section representations to aid the

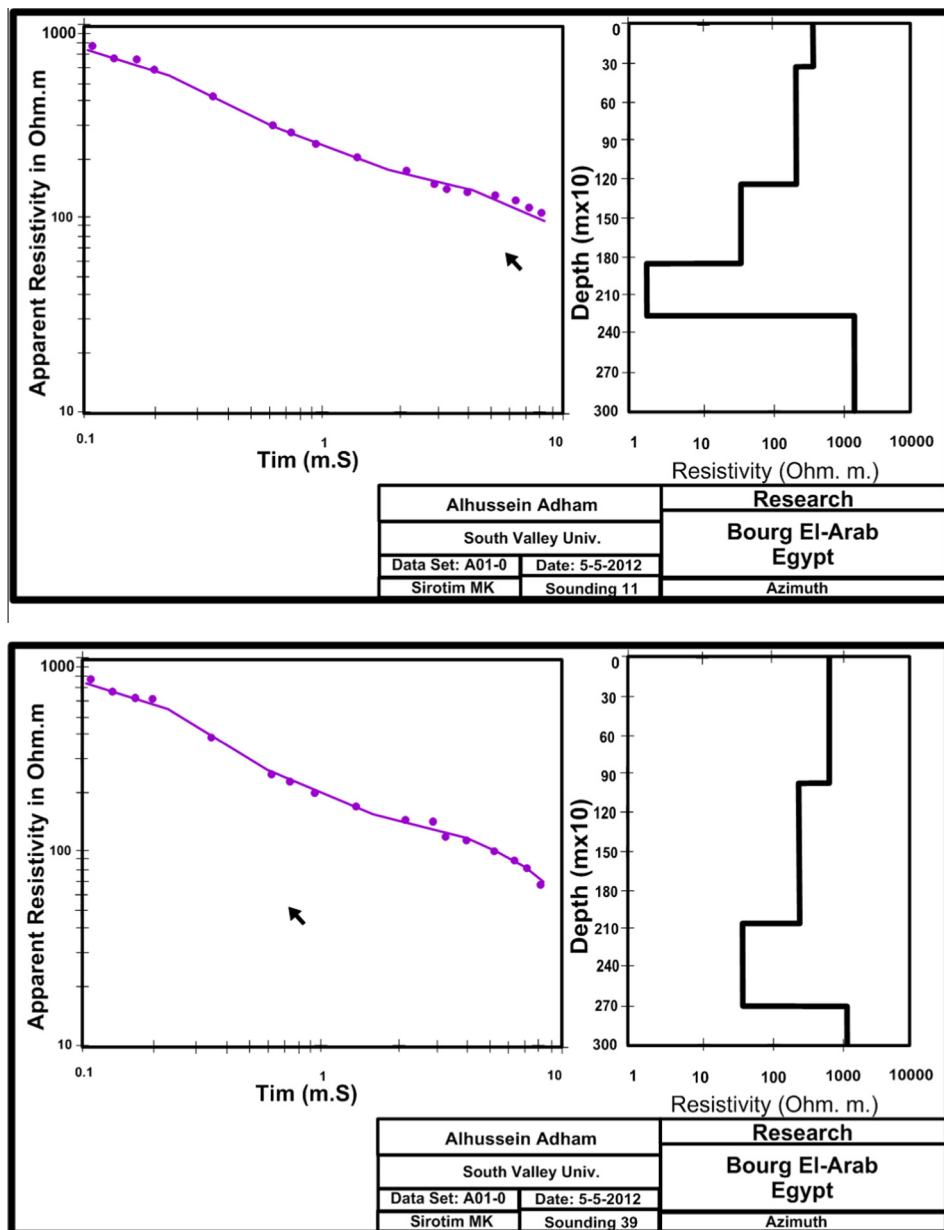


Fig. 8 Example for the interpretation of TEM sounding curve and its interpretation at station No. 11 by TEMIX XL's software.

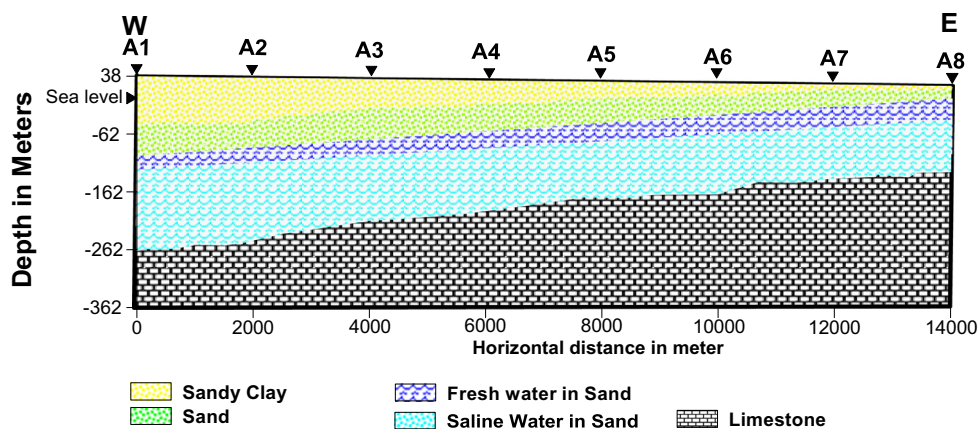


Fig. 9 Geoelectric Cross-section along profile (P1).

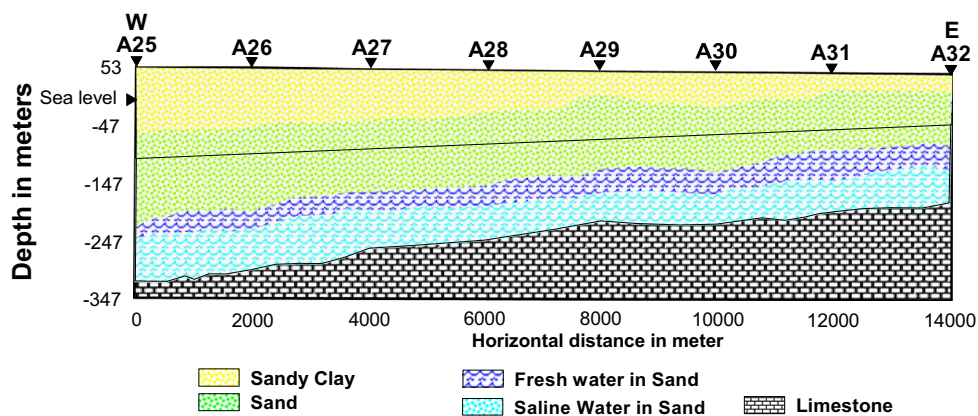


Fig. 10 Geoelectric Cross-section along profile (P2).

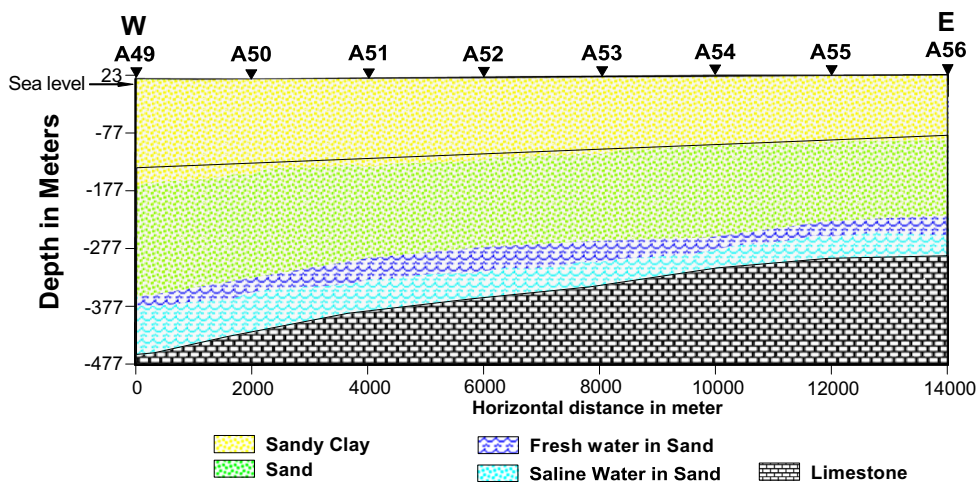


Fig. 11 Geoelectric Cross-section along profile (P3).

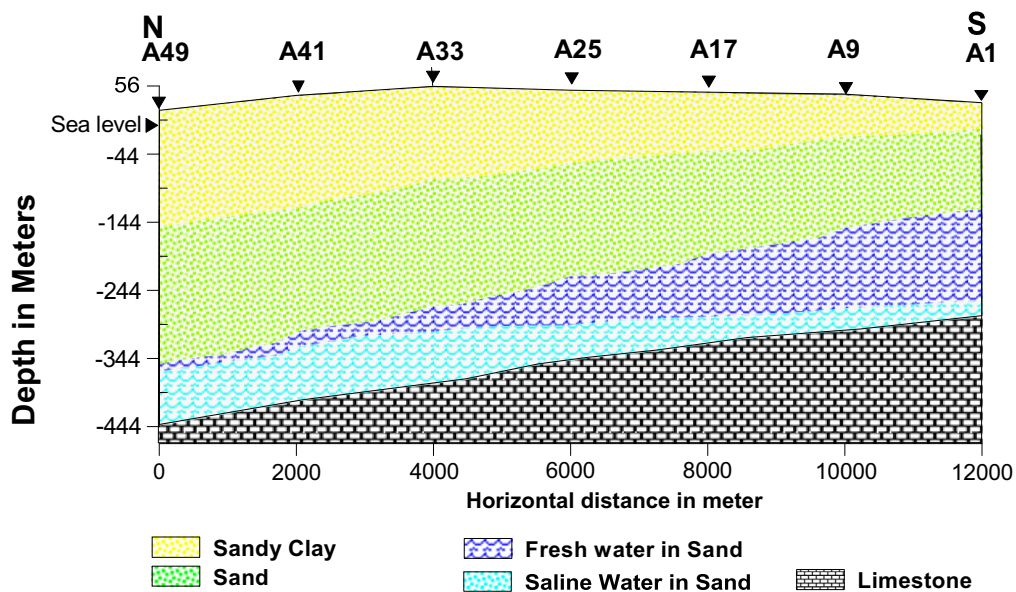


Fig. 12 Geoelectric Cross-section along profile (P4).

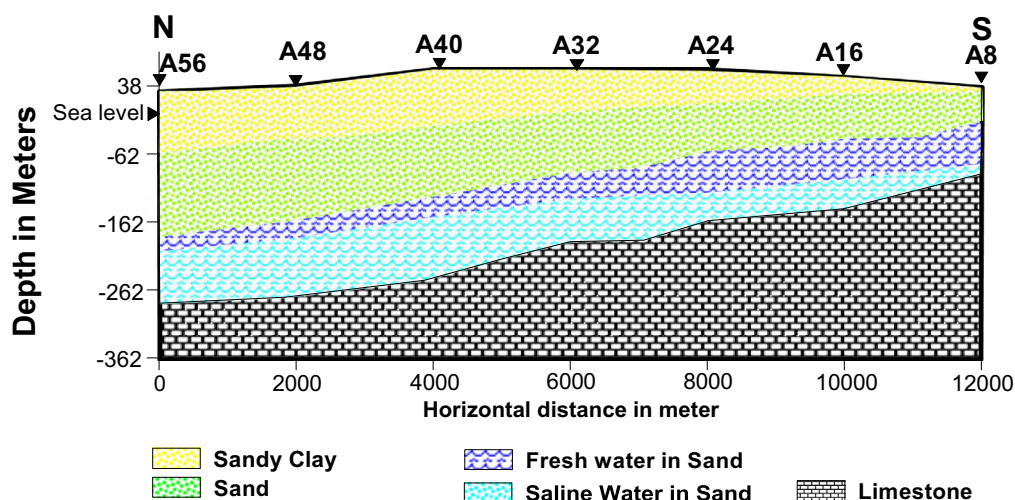


Fig. 13 Geoelectric Cross-section along profile (P5).

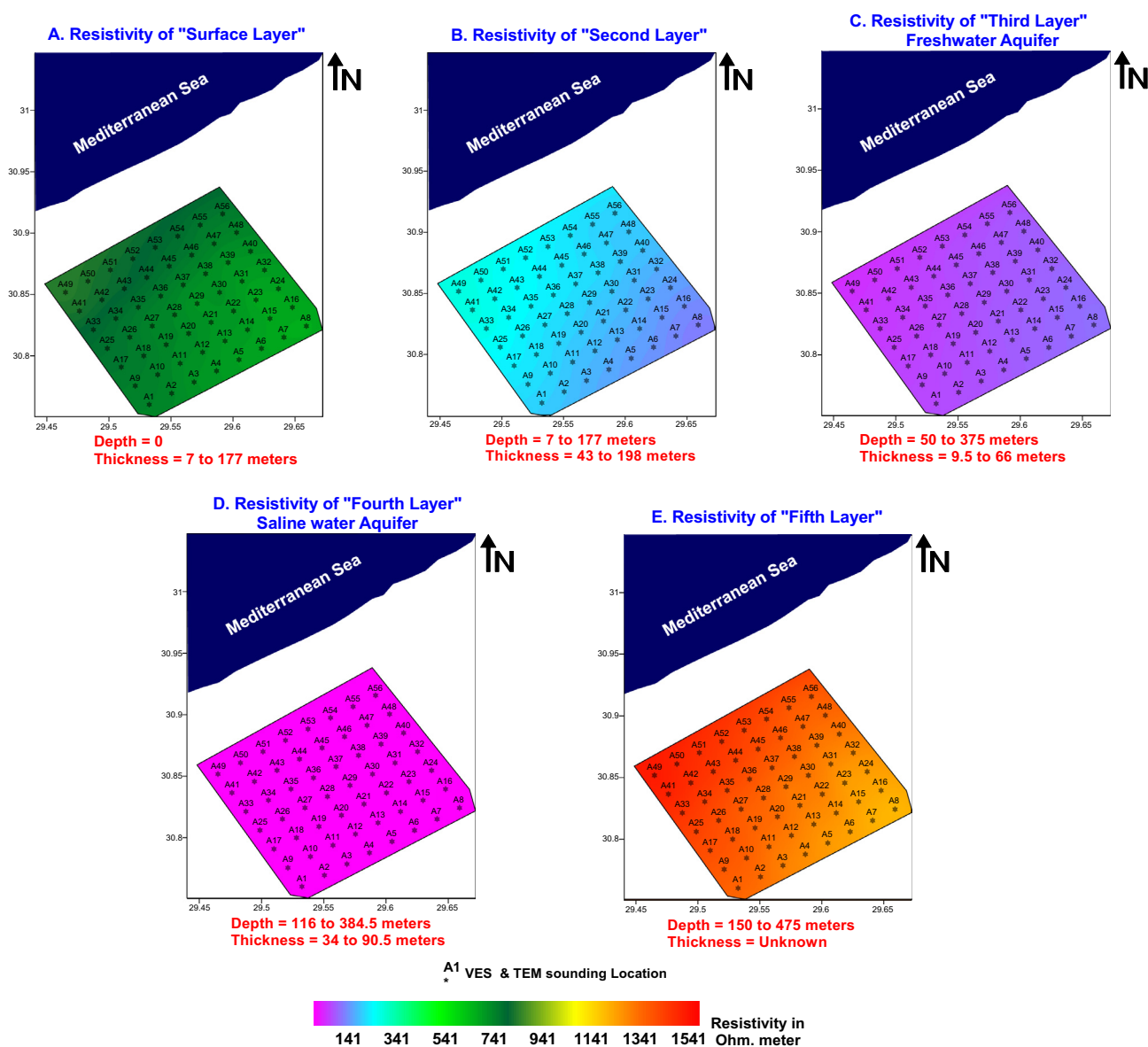


Fig. 14 Maps of the resistivity value distribution for the five layers over the study area.

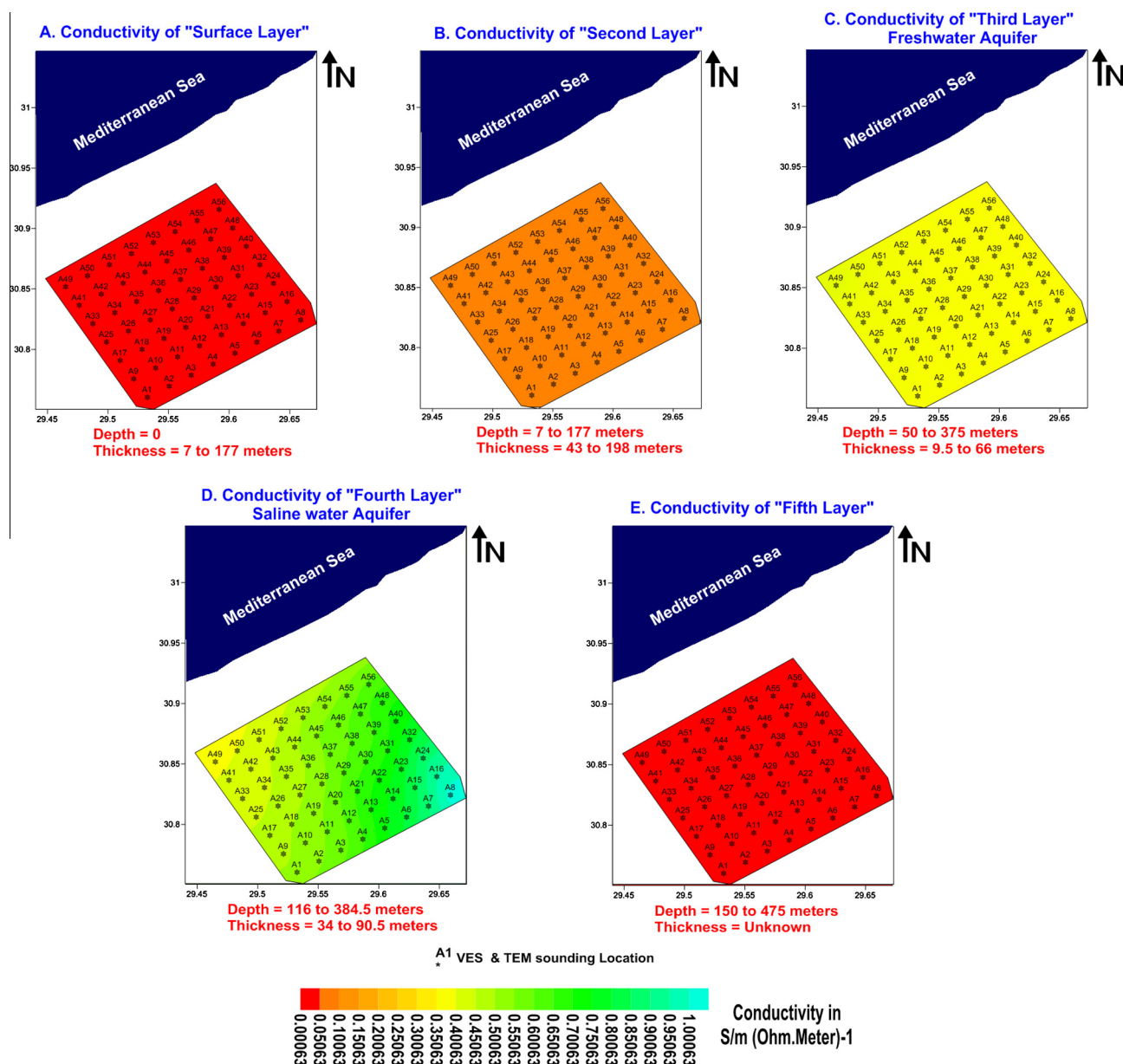


Fig. 15 Maps of the conductivity value distribution for the five layers over the study area.

interpretation. These sections can reveal a good idea about the subsurface geologic and hydro-geologic situations at the study area.

Five geoelectrical cross-sections are constructed along specific three profiles aligned in the E-W direction with nearly constant length that approaches 14,000 m and two profiles aligned in the NW-SE direction with nearly 12,000 m length. The geoelectrical cross-sections have been geared up using the results of the quantitative interpretation of the VES and TEM curves at each station. These results comprise the true resistivity and depth of the layers interpreted at each station. Figs. 9–11 stand for the geoelectrical cross-sections along Profiles P1, P2, and P3 that are elongated in the West–East direction. The geoelectrical cross-sections along Profile P4 and P5 in the North–South direction have been shown in Figs. 12 and 13.

According to the results of both applied techniques, the study area consists of five geoelectrical layers. The first layer composes weathered sandy clay with thickness that varies from 0.5 to 200 m. The second layer consists of sand, this layer has thickness diverging from 40 to 220 m. The third layer composes sand saturated with fresh water, which can be considered as the fresh water aquifer of the study area, the thickness of this aquifer ranges between 9 m in the northeastern part of the study area and 66 m in the southwestern part, this layer reaches its thinnest shape near the sea shore. The fourth layer consists of sand saturated with saline water due to sea water interruption; it can consider the saline water aquifer of the study area. This saline water aquifer has thickness series between 34 and 90 m the fifth layer of the study area composes limestone that belongs to “Miocene” age, this layer appears in depth varying from 150 to 475 m.

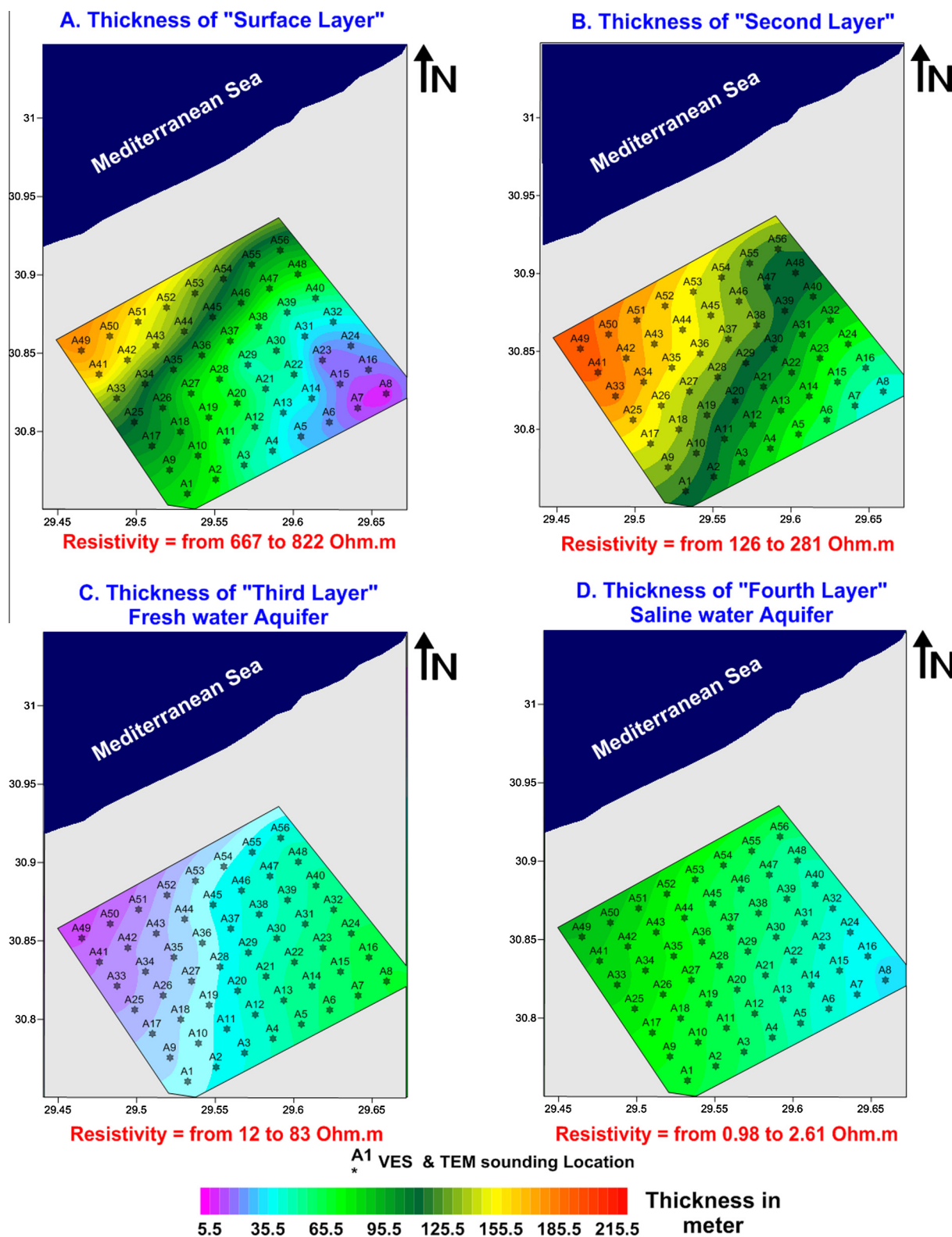


Fig. 16 Maps of the thickness over the different layers of the study area.

## 5.2. Maps

### 5.2.1. Resistivity maps

Five maps have been drawn to illustrate the configuration of the resistivity values in the study area in the five different layers

(Fig. 14). The resistivity values of the first layer varies from 660 to 890 Ohm m, the lowest values reset in the southeastern part of the study area, where the highest values set parallel to the sea shore. These values refer to the gravely sand lithology. The second layer has resistivity values ranging from 120 to

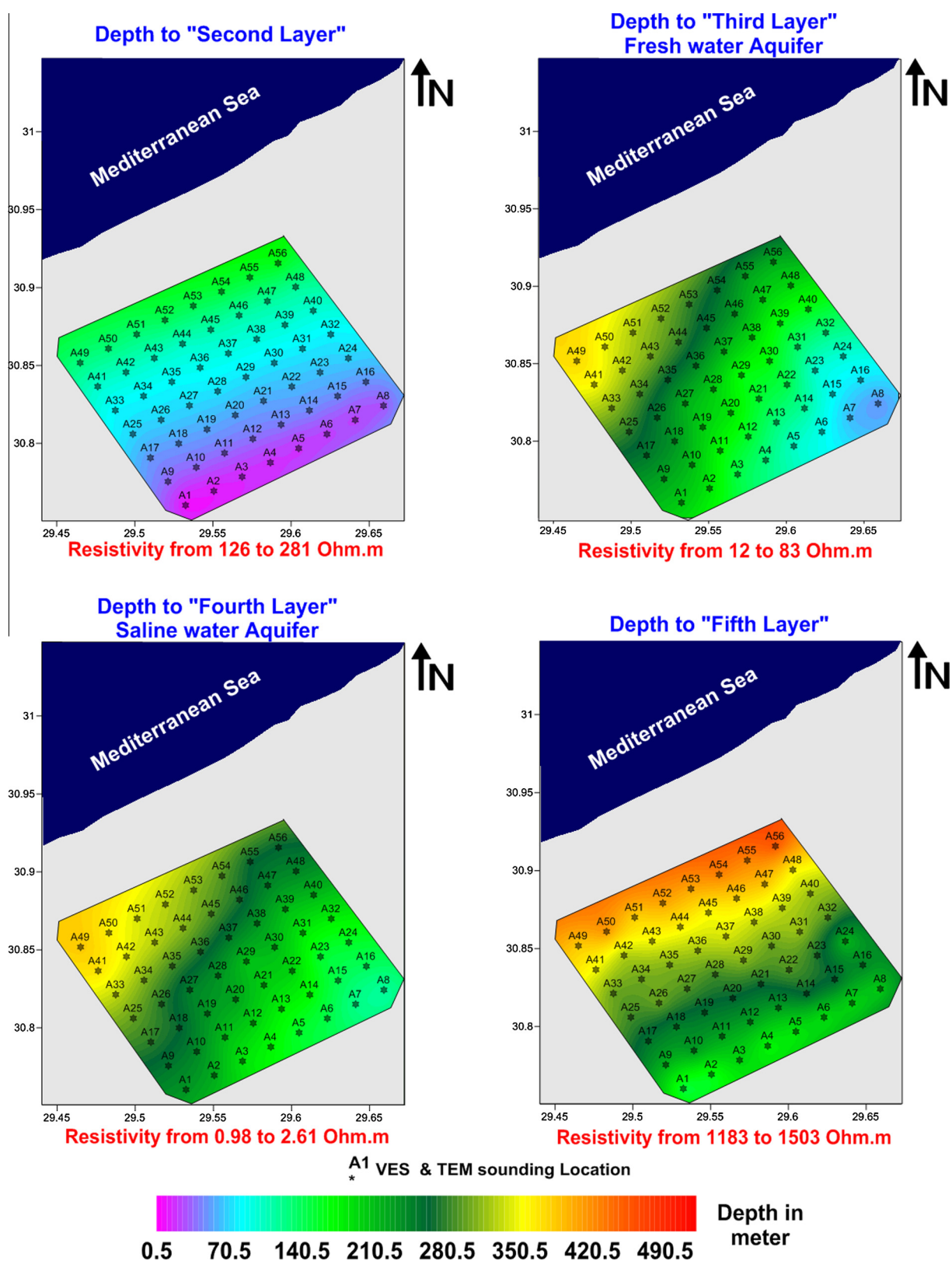


Fig. 17 Maps of the depth over the different layers of the study area.

310 Ohm m, the minimum values placed in the southeastern part of the study area, where the maximum values located in the northern parts parallel to the sea shore. The previous values may refer to sabkha sandy silt and clay lithology.

The third layer, which is considered as the fresh water aquifer of the study area shows resistivity values ranging between 12 and 90 Ohm m, it is noted that this layer thins and disappears near the sea shore. The suitable sites to drill

wells are located in the south and southeastern parts of the study area to extract the fresh water. The lowest resistivity values situated in the southern and southeastern parts of the study area, on the other hand the highest resistivity values placed near the sea shore. These values pass on the sand lithology saturated with fresh water.

The fourth layer has no difference in lithology as sand but, it saturated with saline water. It considers as the saline water aquifer of the study area, where the lowest resistivity values appear in it. These values range from 0.9 to 3.2 Ohm m, the fifth layer that is classified as middle Miocene limestone, has the highest values of the resistivity. These values vary between 1180 and 1590 Ohm m. The maximum values stretch out in the southeastern part of the study area, where the minimum values lie in the northern part parallel to the sea shore in the study area.

#### 5.2.2. Conductivity maps

The same five maps have been drawn but with the conductivity values to show the pattern of the five different layers in the study area (Fig. 15). The conductivity values of the first layer vary from 0.00166 to 0.00112 (Ohm m)<sup>-1</sup>, the highest values reorganize in the southeastern part of the study area, where the lowest values set parallel to the sea shore. These values refer to the gravely sand lithology. The second layer has conductivity values ranging from 0.0083 to 0.0032 (Ohm m)<sup>-1</sup>, the maximum values located in the southeastern part of the study area, where the minimum values positioned in the northern parts parallel to the sea shore. The previous values may due to sabkha sandy silt and clay lithology.

The third layer, which was well thought-out as the fresh water aquifer of the study area shows conductivity values ranging between 0.08333 and 0.0111 (Ohm m.)<sup>-1</sup>, it is distinguished that this layer thins and disappears near the sea shore. The suitable sites to drill wells are placed in the south and southeastern parts of the study area to extract the fresh water. The highest conductivity values positioned in the southern and southeastern parts of the study area, on the other hand the lowest conductivity values placed near the sea shore. These values due to the sand lithology saturated with fresh water.

The fourth layer has no difference in lithology as sand but, it saturated with saline water. It regards as the saline water aquifer of the study area, where the highest conductivity values appear in it. These values vary between 1.1111 and 0.3125 (Ohm m)<sup>-1</sup>, the fifth layer that is known as middle Miocene limestone has the lowest conductivity values. These values range between 8.4745 and 6.2893 (Ohm m.)<sup>-1</sup>. The minimum values widen out in the southeastern part of the study area, where the maximum values laze in the northern part parallel to the sea shore in the study area.

#### 5.2.3. Thickness maps

Thickness maps for first, second, third, and the fourth layers of the study area had been drawn (Fig. 16). The surface layer has thickness ranging between 0.5 and 200 m, the thick branch placed in the northern part of the study area, where the thinnest lies in the southeastern part of the study area.

The second layer shows thickness varying from 40 to 210 m, the thickest values are located in the southeastern corner of the study area. On the other hand the thinnest parts are located in the north and southwestern parts of the study area.

The third layer that is classified as the fresh water aquifer has thickness ranging between 9.5 and 66 m, where the thick parts which are suitable for drilling wells lie in the southeastern corner of the study area, and the thinnest parts are located toward the north and disappear near the sea shore.

The fourth layer illustrates thickness varying from 34 m in the southeastern corner to 90.5 m in the area near the sea shore, this layer is classified as saline water aquifer of the study area.

#### 5.2.4. Depth maps

Four maps have been drawn for the depths of the second, third, fourth, and fifth layers in the study area (Fig. 17). The depth of the second layer varies from 0.5 m in the southern parts to about 200 m in the northern parts of the study area. The third layer has depth ranging between 40 m in the southeastern part and 450 m. in the northern parts of the study area, this layer is classified as the fresh water aquifer. The depth of the fourth layer varies from about 120 m placed in the southeastern part, to about 445 m in the northern parts of the study area. This layer is classified as saline water aquifer. It's noted that the depth to this layer increases toward the sea shore which reveals to the sea water intrusion. The fifth layer that is classified as limestone belongs to Miocene age has depth diverging from about 140 m located in the southern parts to about 450 m located in the northern and southeastern parts of the study area.

## 6. Conclusion

The current study uses Vertical Electrical Soundings (VES'es) and Time Domain Electromagnetic sounding (TEM) to investigate the study area. The study seeks at featuring the main subsurface conditions from the viewpoint of groundwater location, depth and quality. Analysis and interpretation of the obtained results reveal that the subsurface is compounding of five geoelectrical layers with a gentle general slope toward the Mediterranean Sea. The third and the fourth layers in the succession are suggested, according to its true interpreted resistivity and conductivity values, to be the two water bearing formations. The third layer is saturated with fresh water overlying saline water in the bottom of the fourth one. It is worth declaring that the fresh water depth varies between 50 and 354 m under the ground surface. The thickness of the fresh water aquifer varies from 9.5 to 66 m; and the saline water depth varies between 116 and 384 m below the ground surface, the thickness of saline water aquifer differs from 34 to 90.5 m.

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