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The impact of geologic setting on the groundwater occurrence in the Eocene limestone of El Minia-East Nile-Egypt, using geoelectrical technique

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ABSTRACT

The investigated area is a part of the Nile Valley and the surrounding Eocene limestone plateau of central Egypt. It is defined by Latitudes 28º 15′ - 28º 33' N and Longitudes 30º 45- 31º 00′ E, and has a surface area of about 790 Km^2(Figure 1). The geoelectrical resistivity measurements within the present study have been carried out, using the Schlumberger array, to identify the resistivities and thicknesses of the different subsurface layers and to determine their groundwater occurrences. For that reason, 29 Schlumberger Vertical Electrical Soundings were conducted with a maximum half current electrode spacing of 700 m. Results from the quantitative interpretation of the sounding data indicate that the land area is generally underlain by four main geoelectrical units. The main characteristics of these geoelectrical units, as well as the main geologicalfeatures of the constructed geoelectrical cross sections have been interpreted for determining the groundwater occurrences. Based on the results obtained, three water-bearing layers were detected in the investigated area. The Quaternary deposits, which represented by Pleistocene Neonile sediments of sands and gravels with clay and shale lenses (A3) act as the first aquifer. The second one (C4) corresponds to water-bearing limestone of Samalut Formation, which leads to the second aquifer, that represents a wide distribution in the investigated area. The third one (D) corresponds to water-bearing limestone of El-Minia Formation, which leads to the third aquifer and represents a wide distribution in the investigated area. In order to make the geophysical results more useful for the decision maker, two priority maps for groundwater exploitation in the investigated area have been presented for each of El-Minia and Samalut aquifers. According to the priority maps, it can be concluded that, the priority of groundwater occurrences and its exploitations in the study area are generally increasing toward the southern parts, especially at Wadi El Saririia area, where El-Minia aquifer occupies the first category and at Wadi El Sheikh Hasan, where the two main aquifers of Samalut and El-Minia faces are well represented.

Keywords: Schlumberger, Vertical Electrical Sounding (VES), priority maps and Groundwater Occurrences.

INTRODUCTION

The Nile Valley extends between the eastern highly drained and the western slightly drained Eocene Plateaus. The River Nile gets very close to the eastern ridge of the valley. The easternplateau extends from Wadi El Saririia at the southern part up to Wadi Al Nasria at the northern part of the study area. Several wades, which drain the plateau dissect it, in part, into elongated northwest or southwest trends. In the Western Desert, a relatively wide plain separates the undulated uniform surfaced western plateau from the valley. The eastern and western plateaus are formed of massive yellow limestones, chalky limestones, marls and shales of Middle Eocene Samalut, Maghagha and Qarara Formations.

The eastern zone of Nile Valley in the investigated area, with a part of the eastern plateau represents the future urban extension of the crowded population sits on the western side of the Nile River and this area plays an important role for reclamation purposes, where the reclamations are essentially depending on groundwater. Hence, the present study deals with the application of vertical electrical resistivity technique for delineating groundwater aquifers in the investigated area and introducing the suitability of some recommended sites for drilling water wells by constructing the priority maps for water exploitation in the investigated area.

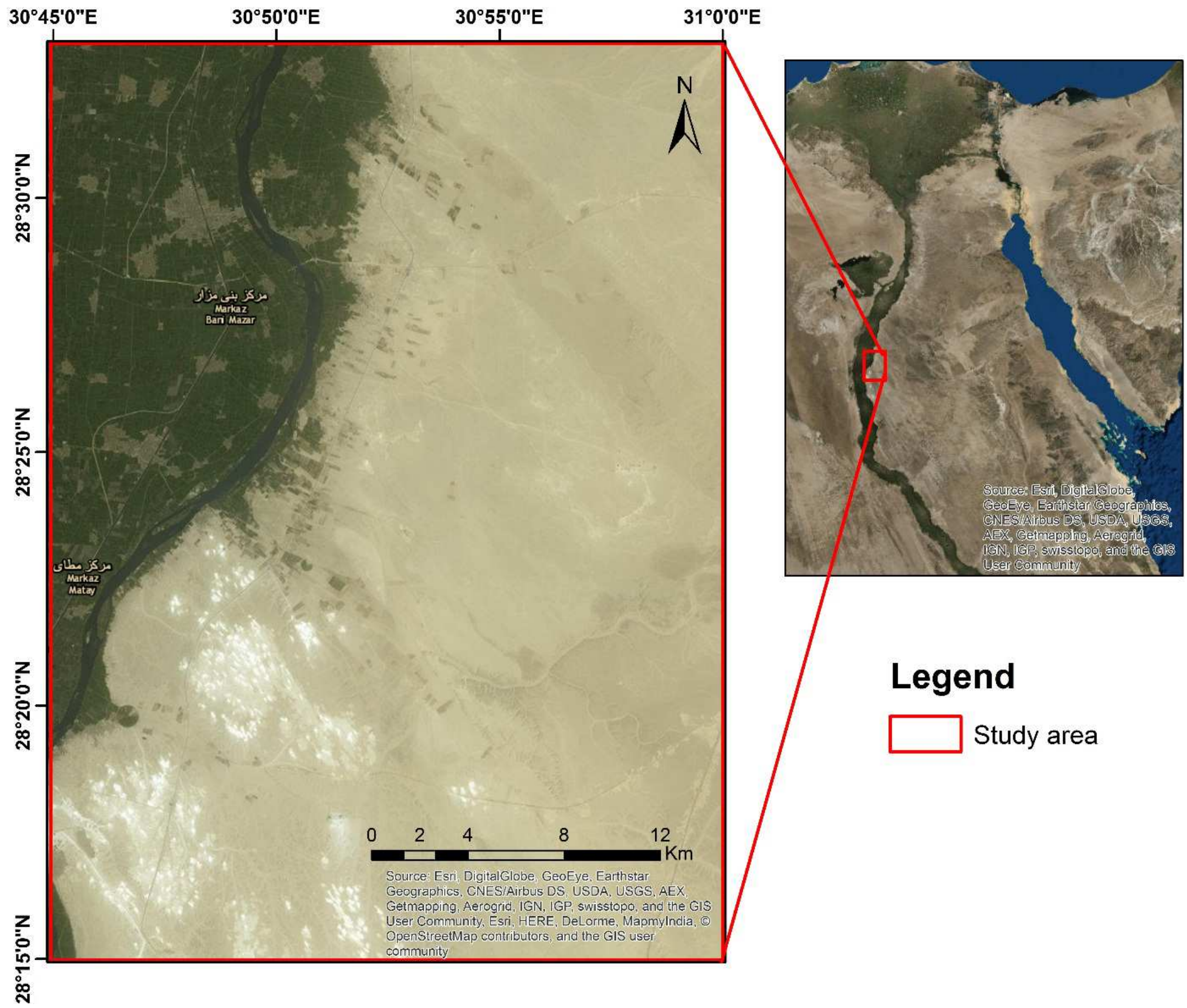

Figure 1: Location map of the investigated area

1.1.Geologic setting:

1.1.1Geomorphologic features:

Egypt can be divided into two main geomorphological regions, which are low plains and elevated structural plateaus[8]. These landscape types play a significant role in determining the hydrogeological framework of Egypt. The structural plateaus are considered as the dead watershedareas, while the low plains contain the main Quaternary aquifer. The area of study lies across the transitional zone between the Nile flood plain and the structural limestone plateaus to the east.

The following geomorphologic features can be recognized (Figure 2) in the study area and its vicinities [6]:

1. Young alluvial plains of the Nile Valley.
2. Old alluvial plains of the Nile Valley.
3. Fanglomerate.

4. Calcareous structural limestone plateau and their sloping boundaries.
5. Sand dunes.
6. Hydrographic patterns.

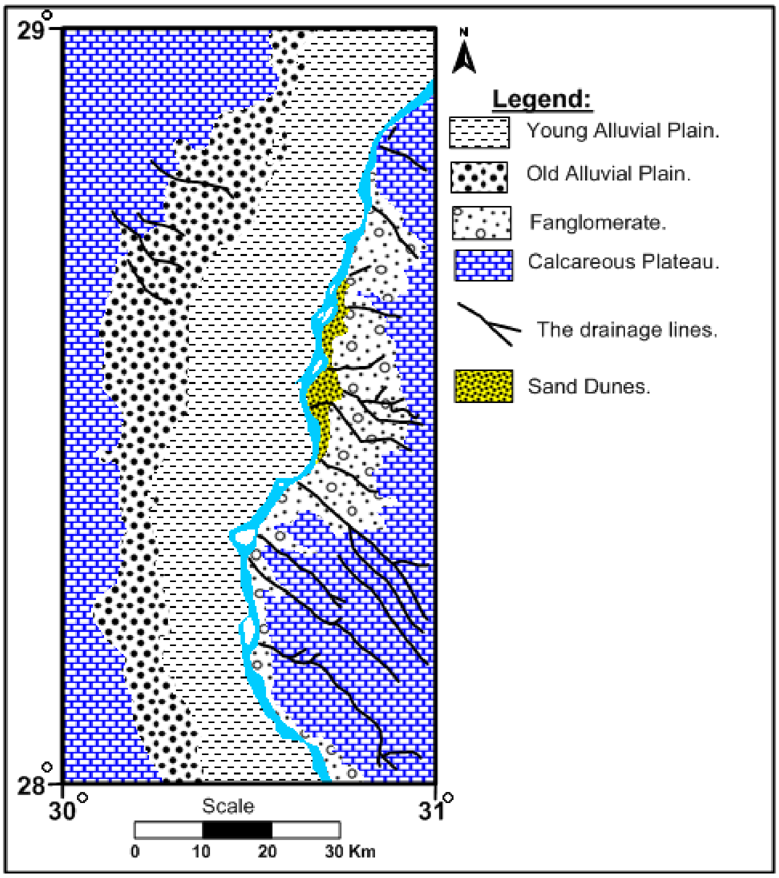

Figure 2: Geomorphologic and drainage features of the study area and its vicinities (After Said, 1981)

1.1.2 Geologic exposures:

El-Minia district and its vicinities are essentially covered by sedimentary rocks ranging in age from Middle Eocene to Recent (Figure3). This area was studied by several workers: e.g. [1,2,3,4,5,6,7,9,10,12]the study area includes three mappable surface rock units of Middle Eocene age[12]. These units are composed mainly of limestone rocks and described from the oldest to the youngest, as follow:

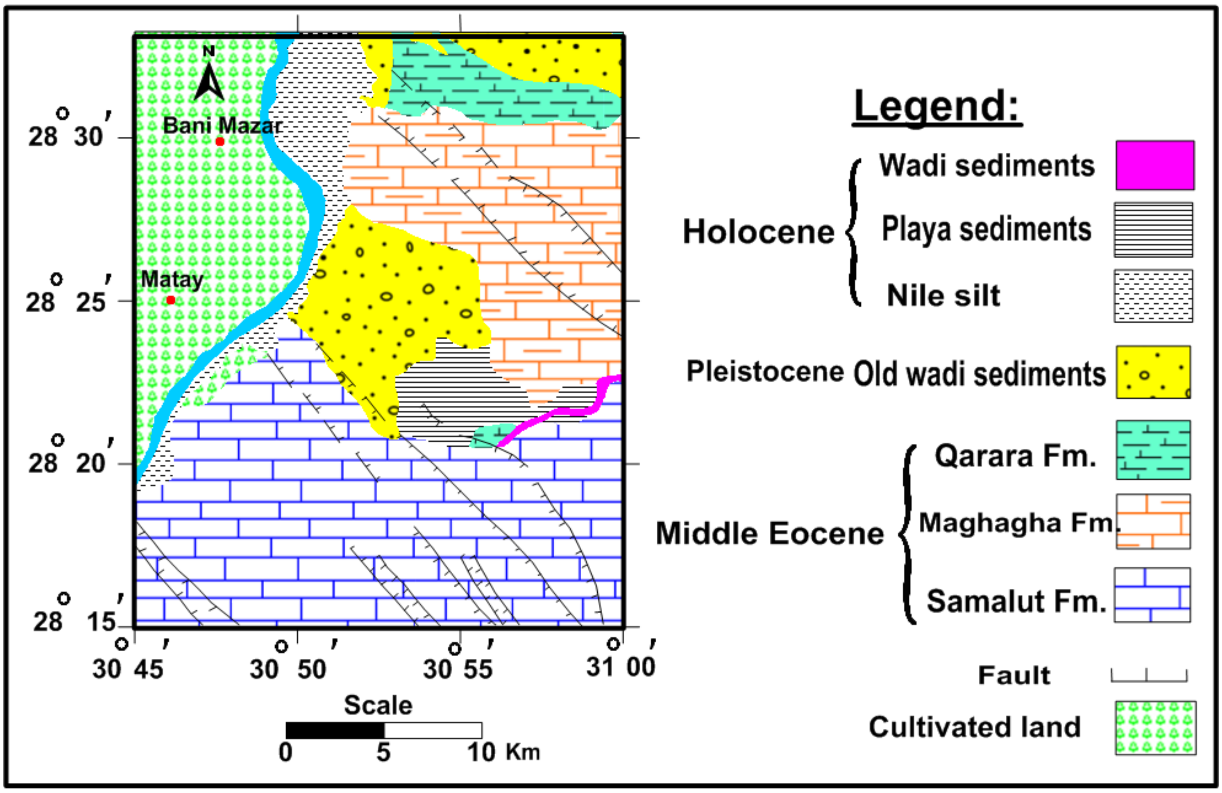

Figure 3:Surface geological map of the study area (After EGSMA et al, 2005)

a. Samalut Formation:

Samalut Formation consists of white limestone and chalky limestone with some marls and claystone interbeds. The average thickness of Samalut Formation reaches about 160 m.

b. Maghagha Formation:

It consists of limestone and marl, with arenaceous marls and shales at the base, intercalated with few calcareous sandstones. The average thickness of Maghagha Formation reaches up to 60 m.

c. Qarara Formation:

The Qarara Formation, of Late Lutenian age, overlies Maghagha Formation. It consists of green and brick-red to brown shale grading upwards into arenaceous marls and siltstone. The average thickness of Qarara Formation reaches about 170 m.

1.1.3 Structural elements:

The valley was probably eroded on fault lines[1] and bounded on both sides by steep slopes made up of Eocene limestone, most probably accompanied by normal faults[6]. Major normal faults have general NW_SE and NE_SW directions. These faults are observable on the surface, as well as they are encountered from the subsurface borehole data, below the Quaternary deposits [9]

MATERIALS AND METHODS

A total of twenty nine Schlumberger-Vertical Electrical Soundings were conducted along the different available wades in the investigated area with a maximum half current electrode spacing (AB/2) of 700 m. This electrode separation is sufficient to reach the required depth, which fulfills the aim of the study. In order to verify the geoelectrical interpretation results, some of the sounding measurements were carried out beside or near some of the existing wells, which the lithologic and hydrologic data are available. These vertical electrical soundings have been carried out by ABEM terrameter SAS 1000C, as Swedish apparatus.

The apparent resistivity measurements at each station were plotted against the half current electrode spacing (AB/2) on a bi-logarithmic graph sheets. The curves obtained were matched using master curves and auxiliary curves and were inspected to determine the number and nature of geoelectrical layers, as a semi-quantitative interpretation. The results of curve matching (layer resistivities and thicknesses) were fed as preliminary models in an iterative forward modeling technique, using the IPI2Win computer program[11]. This is to vindicate the correlation between the field curves and theoretical curves. From the interpreted results (layer resistivities and thicknesses); geoelectric sections were drawn using Grapher software.

RESULTS AND DISCUSSION

The measured vertical electrical sounding locations are illustrated in (Figure4) and the interpretation of the acquired resistivity sounding data is carried out in quantitative phase. The steps followed in the interpretation of the acquired data quantitatively are:

3.1. Quantitative interpretation:

The interpretation of vertical electrical sounding curves exhibits that, the number of interpreting units isfour which divided into layers, and the true resistivities of these layers range between 0.9 Ω. m and 9898 Ω. m Also, the thicknesses of these layers vary from a sounding station to another. The interpretations of some vertical electrical sounding curves with the true resistivities and thicknesses of the study area are selected and shown in (Figure 5).

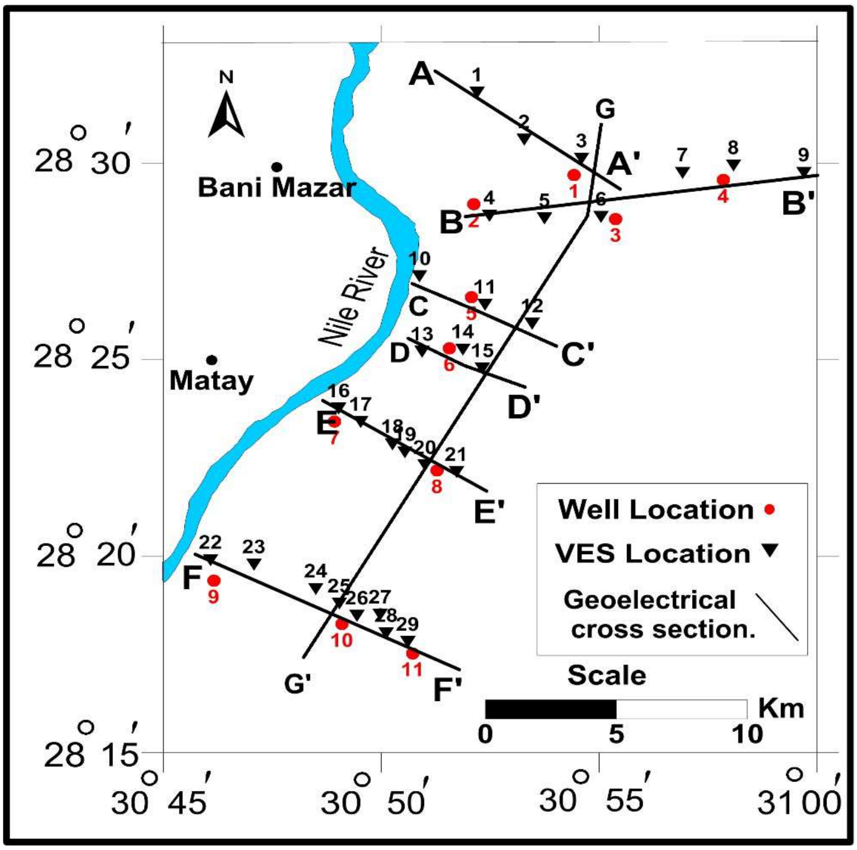

Figure 4: VESes locations and cross sections distribution in the study area

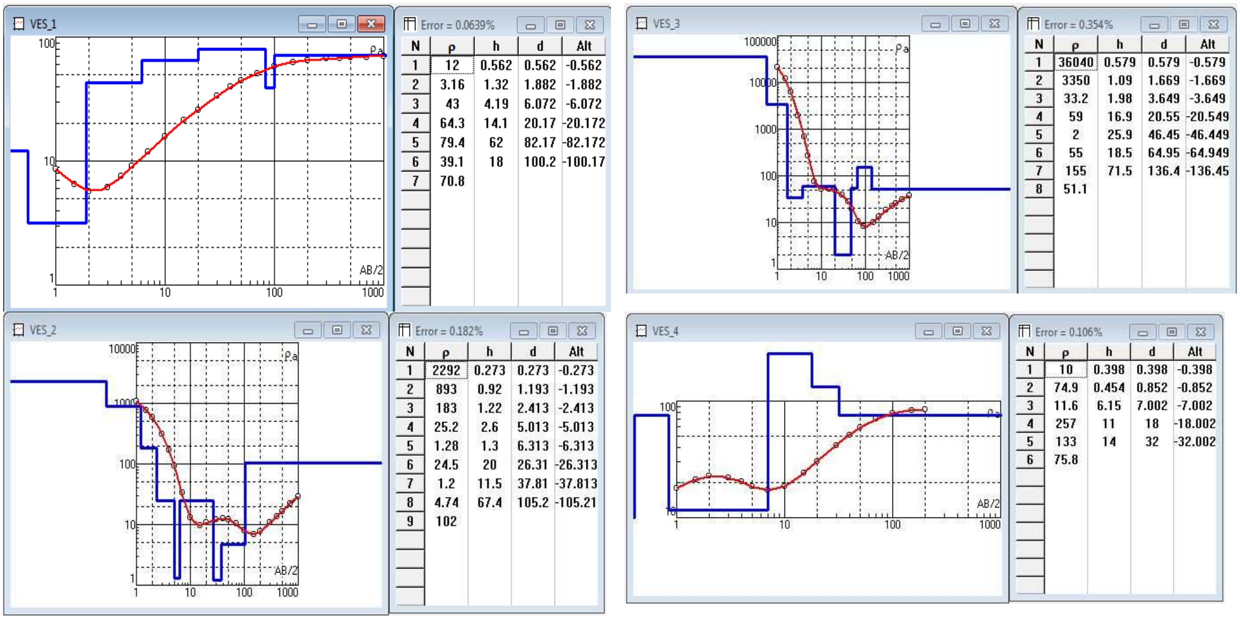

Figure5: Some of the interpreted vertical electrical sounding curves with true resistivities (ρ) and thicknesses (h) of each layer

3.1.1. Geoelectrical cross sections

Based on the results of the interpreted vertical electrical soundings, seven geoelectrical cross sections (Figure4) have been constructed (Figs.Nos.6to12). The aim of these sections is to show the geoelectric layers and the geometry of the aquifers and their extensions in the area. These sections reflect both the lateral and vertical variations in lithologies, according to the resistivities. The bore holes (where these wells drilled by villagers), which present in the area, were also used to calibrate the geoelectrical deductions.

The quantitative interpretation of the resistivity soundings led to the detection of four main geoelectrical units, which divided into layers. The ranges of resistivities and thicknesses of each unit are listed in (table 1). A description of these units is given, as the following:

Table 1: Resistivities, thicknesses range s and their related lithology

Unit	Layer	Resistivity range (Ohm m)	Thickness (m)	Lithology
"A"	A1	83 – 9898	0.3 - 11	Gravels, boulders and sands
	A2	7 – 33	1 – 18	Nile silts and clays.
	A3	2 -10	---	Water-bearing sands and gravels, with clay and shale lenses.
	A4	119 - 2689	1 - 6	Old wadi sediments.
"B"	B1	210 - 1500	3 - 25	Dry limestones of Maghagha Formation.
	B2	11 – 77	5 - 30	Marly limestones of Maghagha Formation.
	B3	0.9 – 9	8.5 - 78	Shales of Maghagha Formation.
"C"	C1	200 – 2900	5 - 38	Dry limestones of Samalut Formation.
	C2	46 – 153	1.3 – 5.7	Chalky limestones of Samalut Formation.
	C3	14 – 26	4 - 18	Claystones of Samalut Formation.
	C4	30 – 200	19 - 110	Water-bearing limestones of Samalut Formation.
	C5	2.8 - 9.8	10 - 33	Shales of Samalut Formation.
"D"		50 – 190	---	Water-bearing limestones of El-Minia Formation.

- **The first geoelectrical unit (A)**:

This unit is differentiated into four layers (A1, A2, A3 and A4) and their equivalent facies are of Quaternary deposits.

a) The geoelectrical layer (A1) has resistivity values ranging between 83 and 9898 Ω.m, correspond to gravels, boulders and sands of the Quaternary deposits. The thicknesses of this layer vary from 0.3 to 11 m.

b) The geoelectrical layer (A2) is observed along the eastern part of the Nile River in the study area. This layer displays relatively low resistivity rang varying from 7 to 33 Ω.m, and correspond to nile silts and clays of Quaternary deposits. The thicknesses of this layer varying from 1to18m.

c) The third geoelectrical layer (A3) displays relatively low resistivity values varying from 2 to 10 Ω.m, correspond to water-bearing neonile deposits, which consist of sands and gravels with clay and shale lenses and represents the first aquifer in the study area.

d) The fourth geoelectrical layer (A4) has resistivity values ranging from 119 to 2689 Ω.m, correspond to dry old wadi sediments of Quaternary deposits. The thickness of this layer varies from 1 to 6 m.

- **The second geoelectrical unit (B)**:

This unit is located underlying the first geoelectrical unit, which differentiated into three layers (B1, B2 and B3),and their equivalent facies of Maghagha Formation of the Middle Eocene.

a) The geoelectrical layer (B1) covers small part of the study area. The resistivity values of this layer vary from 210 to 1500 Ω.m, correspond to dry limestone of Maghagha Formation. The thickness of this layer varies from 3 to 25 m.

b) The geoelectrical layer (B2) has resistivity value varies from 11 to 77 Ω.m, correspond to marly limestone of Maghagha Formation.The thickness of this layer varies from 35 to 30 m 24.

c) The geoelectrical layer (B3) displays a relatively low resistivity values vary from 0.9 to 9 Ω.m, correspond to shale of Maghagha Formation. The thickness of this layer varies from 8.5 to 78 m.

- **The third geoelectrical unit (C):**

This unit is located underlying the second geoelectrical unit, which differentiated into five layers (C1, C2, C3, C4 and C5), and their equivalent facies are of Samalut Formation of Middle Eocene.

a) The geoelectrical layer (C1) displays relatively high resistivity values ranging between 200 and 2900 Ω.m, correspond to dry limestones of Samalut Formation. The thickness of this layer varies from 5 to 38 m.

b) The geoelectrical layer (C2) is observed at the southern part of the study area,which represents small distribution in the study area. This layer has resistivity values ranging between 46 and 153 Ω.m, correspond to chalky limestones of Samalut Formation. The thickness of this layer varies from 1.3 to 5.7 m.

c) The geoelectrical layer (C3) has resistivity values ranging between 14 and 26 Ω.m, correspond to claystones of Samalut Formation. The thickness of this layer varies from 4 to 18 m.

d) The geoelectrical layer (C4) covers most parts of the study area. It has resistivity values varing from 30 to 200 Ω.m, correspond to water-bearing limestones of Samalut Formation, which represents the second aquifer in the study area. The thickness of this layer varies from 19 to 110 m.

e) The geoelectrical layer (C5) is observed at the southern part of the study area, which represents small distribution in the study area. This layer displays relatively low resistivity values varies from 2.8 to 9.8 Ω.m, correspond to shales of Samalut Formation. The thicknesses of this layer varies from 10 to 33 m.

- **The fourth geoelectrical unit (D)**:

This layer represents a wide distribution in the study area and has resistivity values vary from 50 to 190 Ω.m, correspond to water-bearing limestone of El-Minia Formation, which represents the third and last aquifer in the study area.

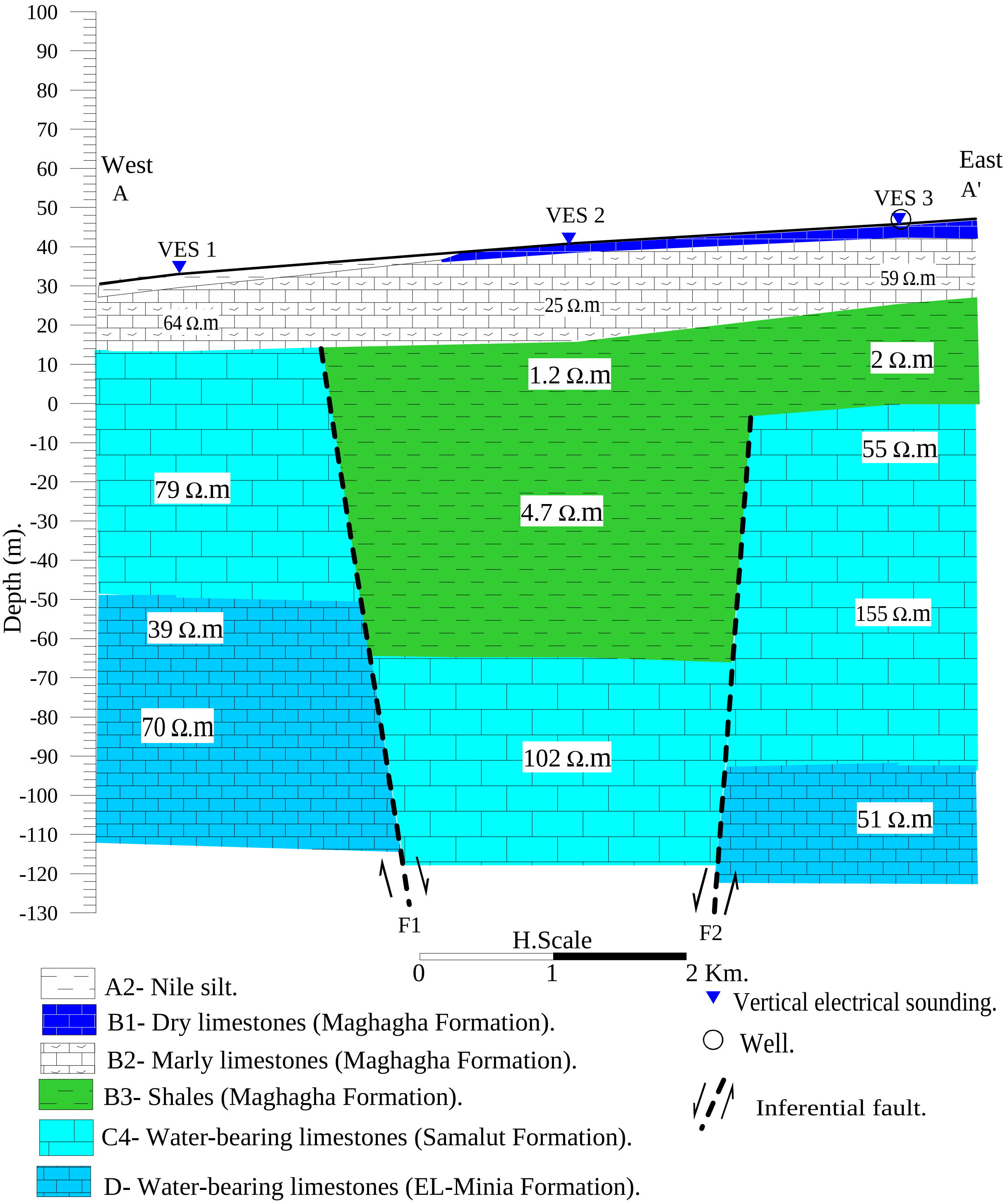

Figure 6: Geoelectrical resistivity cross–section A-A'

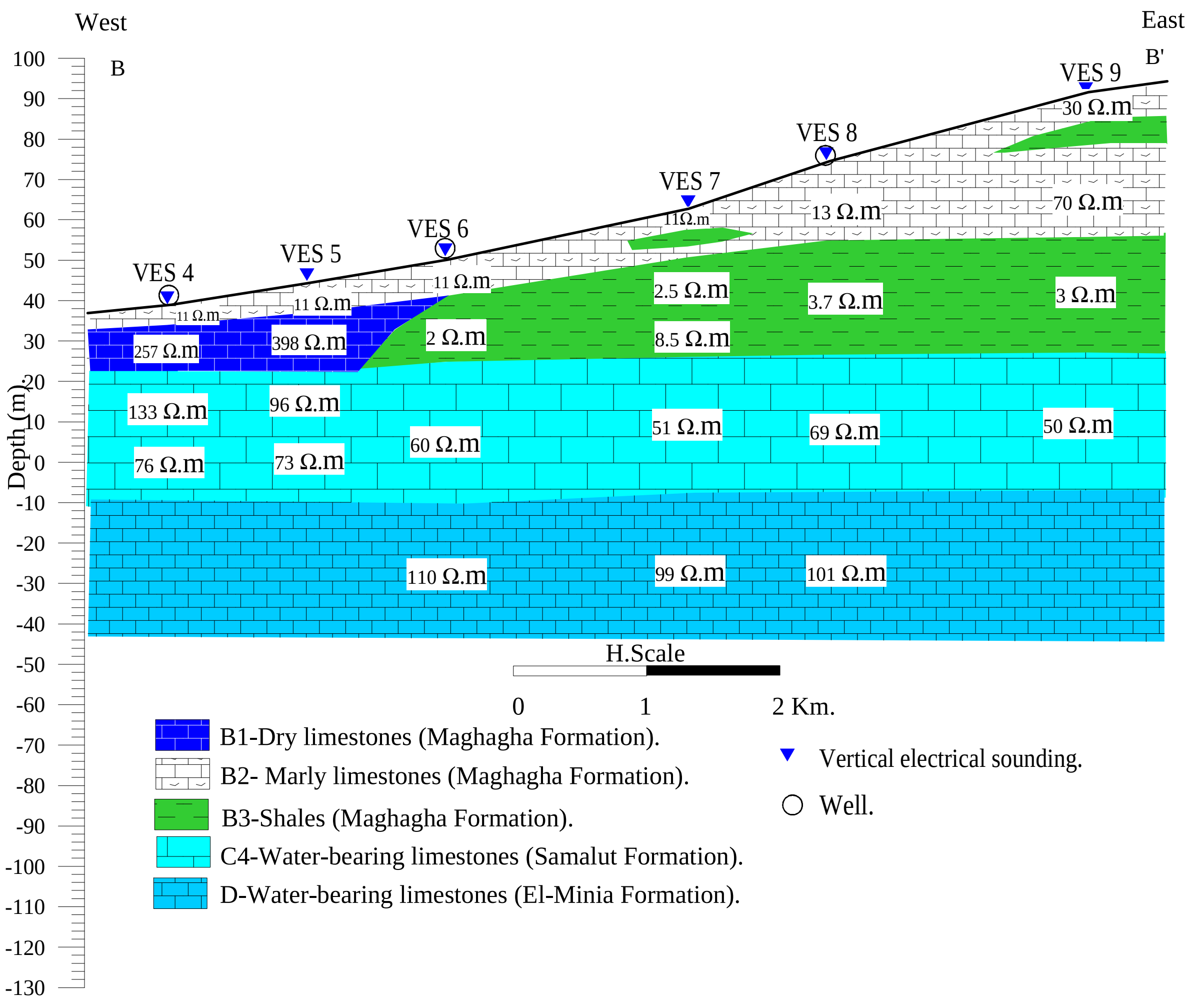

Figure7: Geoelectrical resistivity cross–section B-B'

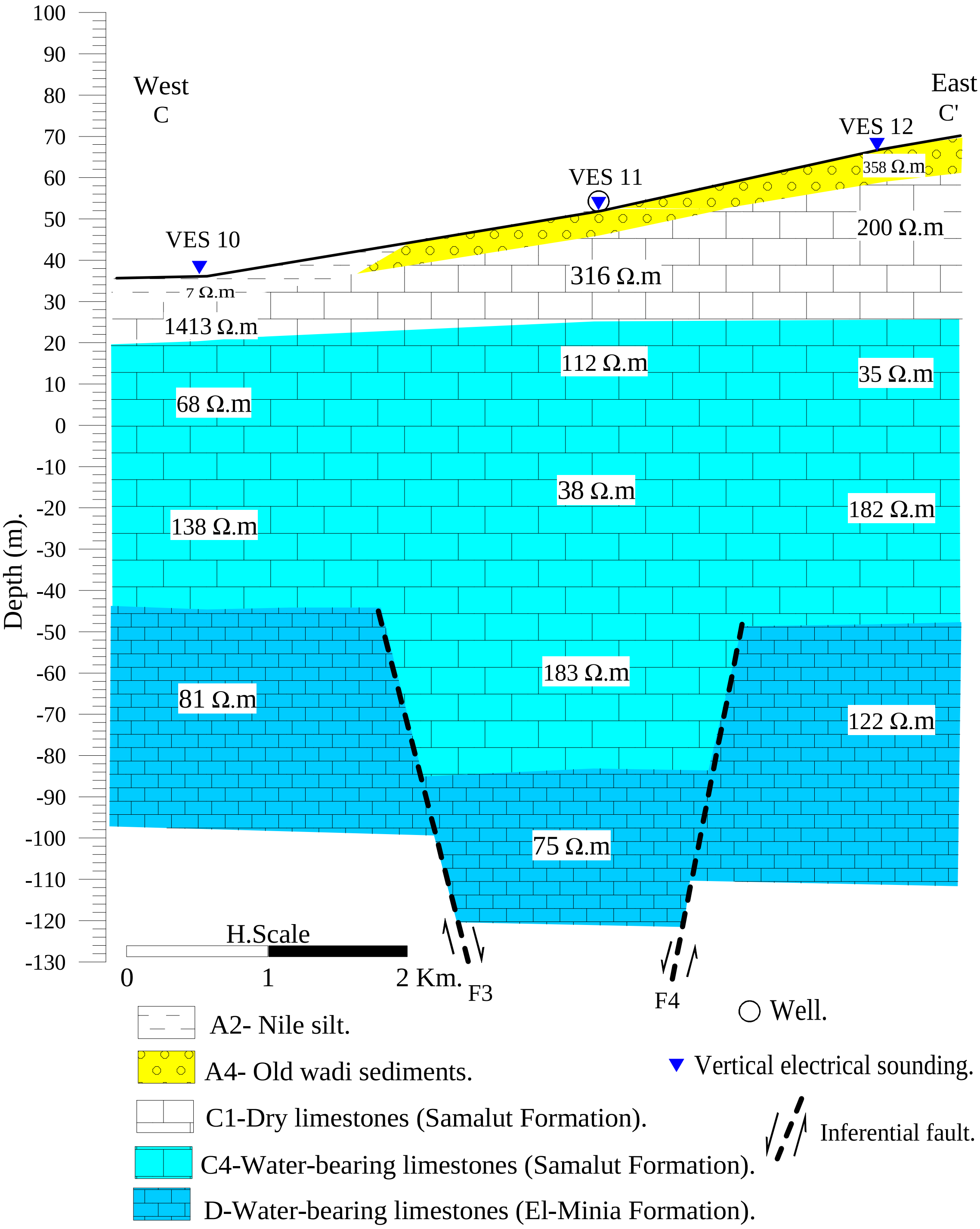

Figure 8: Geoelectrical resistivity cross–section C-C'.

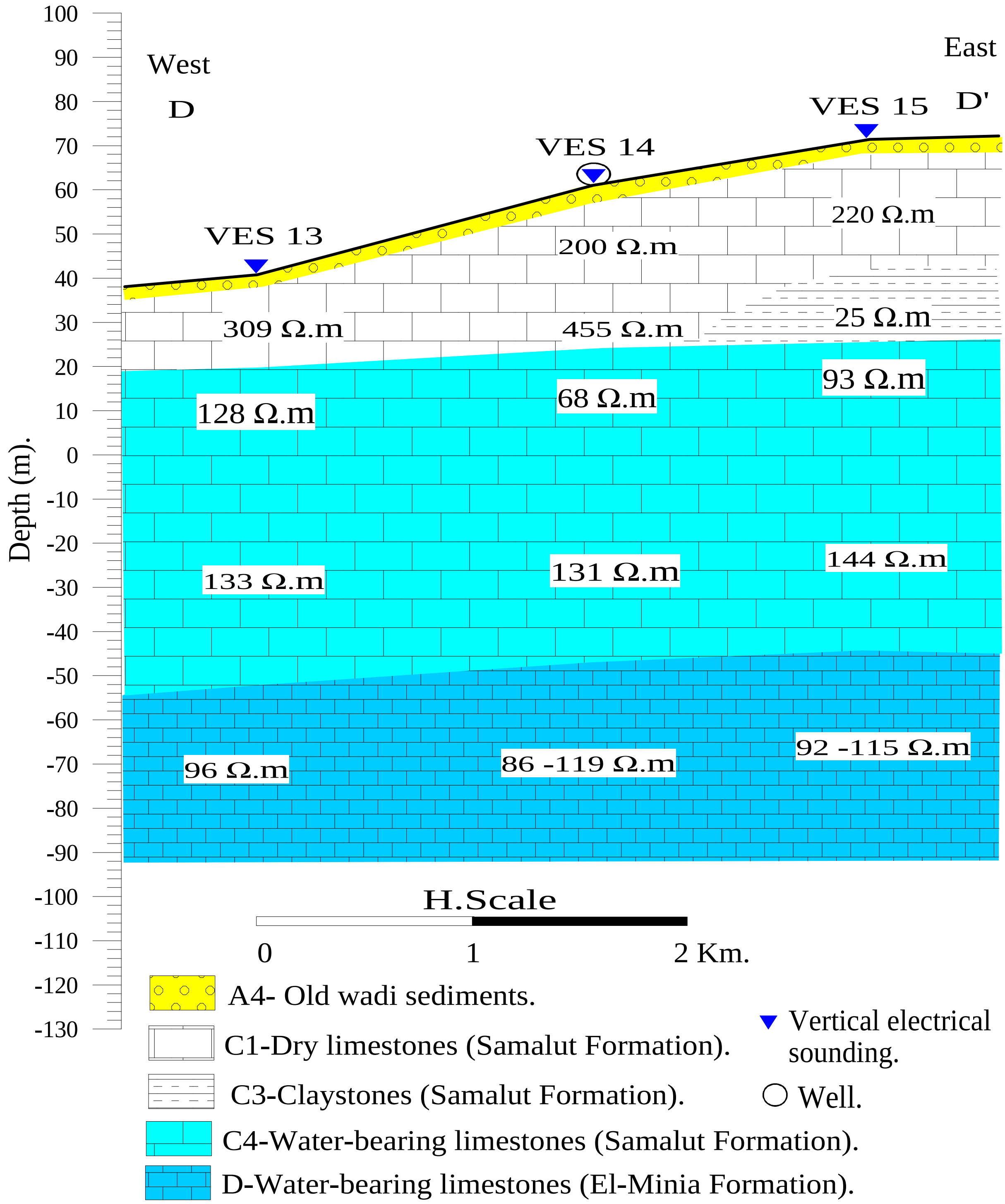

Figure 9: Geoelectrical resistivity cross–section D-D'

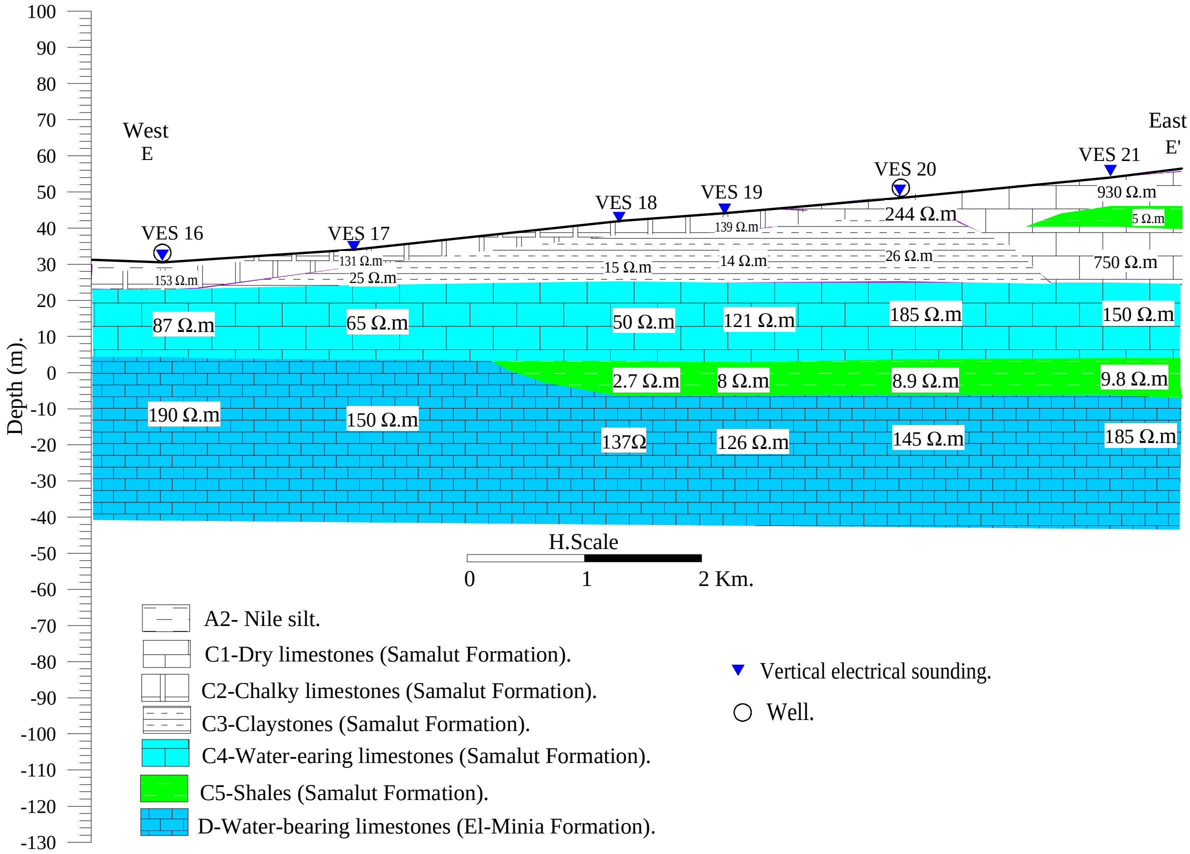

Figure 10: Geoelectrical resistivity cross–section E-E'

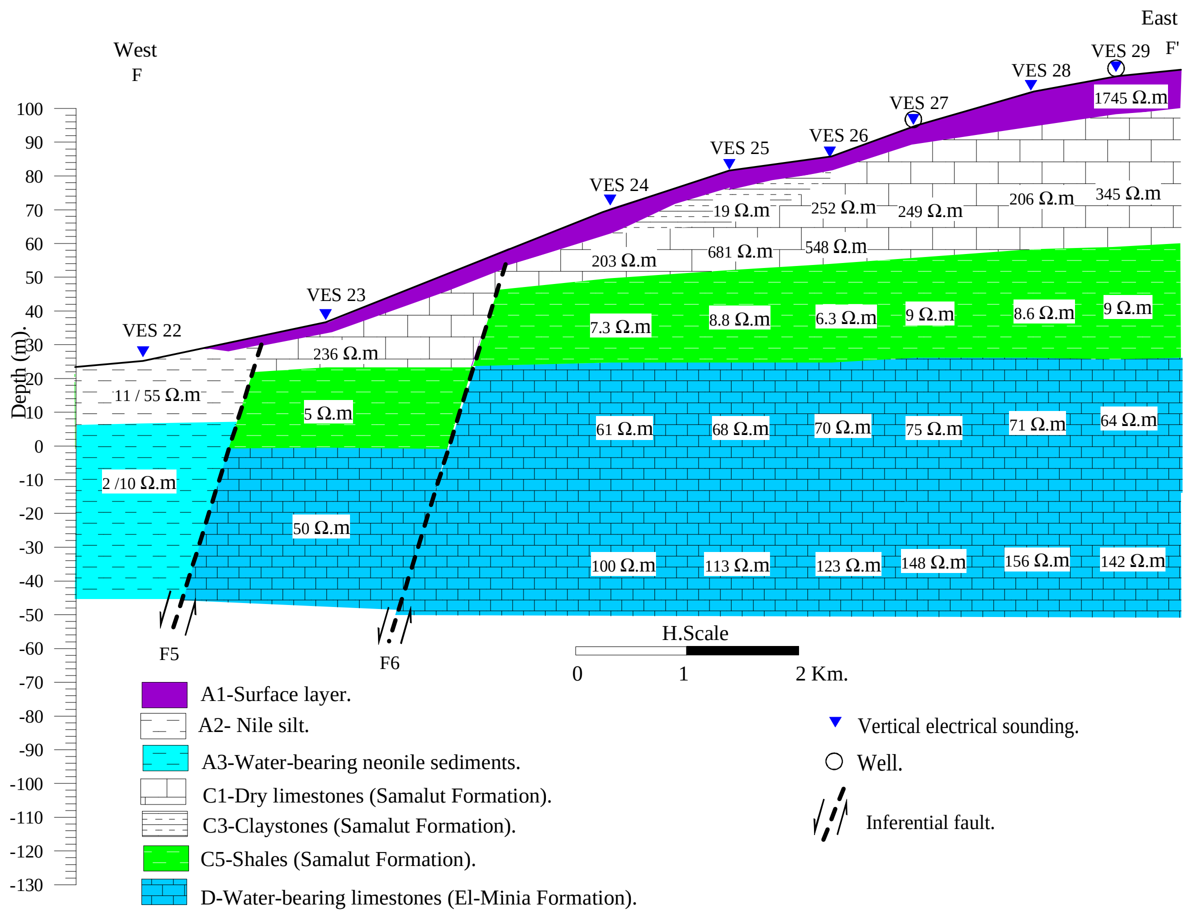

Figure 11: Geoelectrical resistivity cross–section F-F'

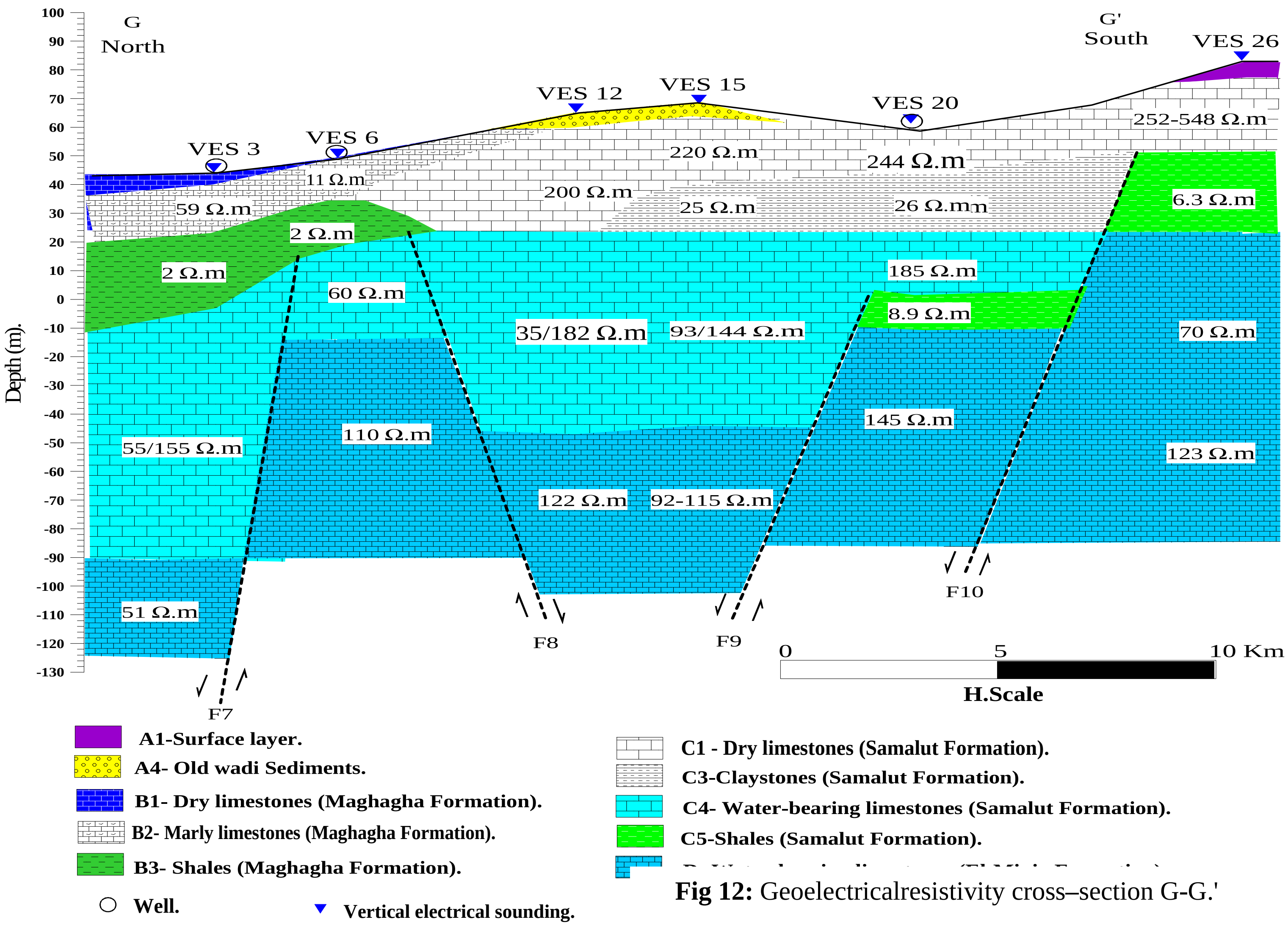

Fig 12: Geoelectricalresistivity cross–section G-G.'

3.1.2. Structuralmap:

The lithologic successions from surface to base are affected by a group of inferential normal faults (Figure13),that have a direct effect on the shape of the surface terrain and groundwater occurrences. The cross section A-A' has two normal faults F1 and F2 that act as a graben block, the cross section C-C' has two normal faults F3 and F4 that act as a graben block, the cross section F-F' has two normal faults F5 and F6that act as a step-like form, while the longitudinal cross section G-G' has four normal faults (F7, F8, F9 and F10) that act as horst, graben and step-like forms.

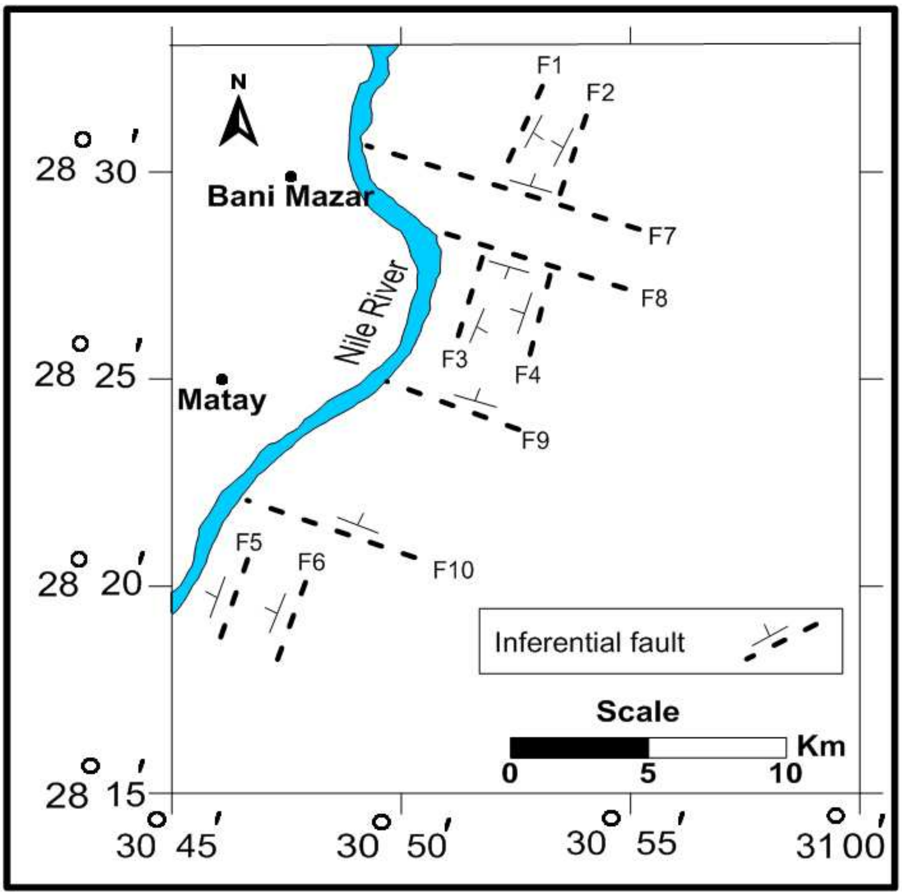

Figure13: Structuralmap

3.1.3 Priority map for groundwater exploitation of Samalut aquifer (C4):

Generally, a priority map has been generated for exploiting the geoelectrical water-bearing layer C4 in the case of drilling deep wells. This map defines the zones of different priorities for groundwater exploitation. There are not abrupt changes in the resistivities and thicknesses of this layer. Since, the depth to water plays a significant role in groundwater utilization, consequently the weighting factors of the depth to water, resistivity, and thickness of water-bearing layer are 60%, 20% and 20%, respectively. These factors are essential for the construction of such map. The resistivity, thickness and depth to water have been integrated into three options, as shown in (table 2).

The groundwater priority map for Samalut aquiferC4 in the investigated area (Figure14)indicates that, the most promising area for drilling water well, located at the part between the central and Southern parts. The second site for drilling well is located at the central part and extends along the Nile River. Finally, the third site for drilling is located at the area between the central and northern parts (Figure14).

3.1.4. Priority map for groundwater exploitation of El-Minia aquifer (D):

Generally, a priority map has been generated for exploiting the geoelectrical water-bearing layer E in the case of drilling deep water wells. This map defines the zones of different priorities for groundwater exploitation. The base of this water-bearing layer has not been recorded. Since, the resistivity and depth to water play, a significant role in groundwater utilization, consequently the weighting factors of the depth to water and resistivity of water-bearing layer are 70% and 30% respectively. These factors are essential for the construction of such map. The resistivity and depth to water have been integrated into three options, as shown in (table 3).

The groundwater priority map for El-Minia aquiferin the investigated area(Figure15)indicates that, the most promising site for drilling well tapping is located at the extremely southern part, where wadi El Saririia area. The second site for drilling is located at the area between the central and southern parts.

Finally, the third area for drilling is located at the area between the central and northern parts (Figure15).

In the light of this study, it can be concluded that, the priorities of groundwater occurrences and their exploitations in the study area generally increase toward the southern parts, especially at wadi El Saririia area, where-El Minia aquifer occupies the first category, and at Wadi El Sheikh Hasan, where the two main aquifers of Samalut and El-Minia Formations are well represented.

Table 2: Resistivity, thickness and depth to water category ranges for Samalut aquifer

Category	Resistivity (ρ) ranges (Ω)	Thickness (h) ranges (m)	Depth to water (D) ranges (m)
1	$30 \le \rho < 87$	$105 \ge h > 76$	$10 \le D < 44$
2	$87 \le \rho < 144$	$76 \ge h > 48$	$44 \le D \le 77$
3	$144 \le \rho \le 200$	$48 \ge h \ge 20$	$77 \le D \le 110$

Table 3: Resistivity and depth to water category ranges for El-Minia aquifer

Category	Resistivity (ρ) ranges (Ω)	Depth to water (D) ranges (m)
1	$50 \le \rho < 97$	$25 \le D < 75$
2	$97 \le \rho < 144$	$75 \le D < 125$
3	$144 \le \rho \le 190$	$125 \le D \le 175$

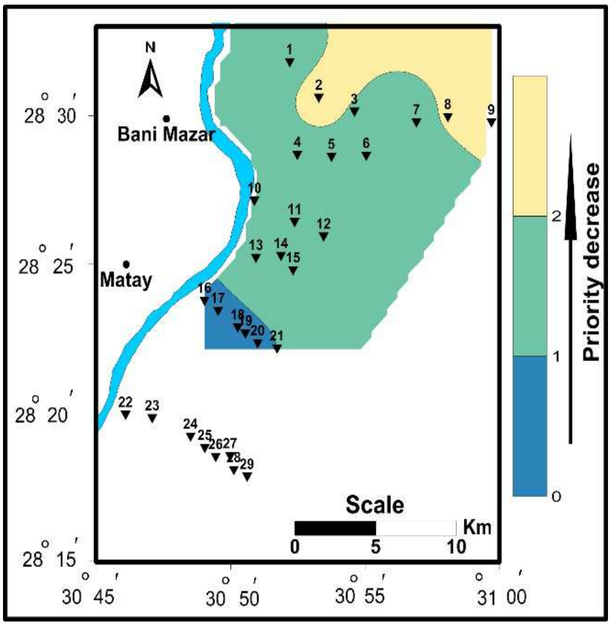

Figure14: Priority map for Samalutaquifer

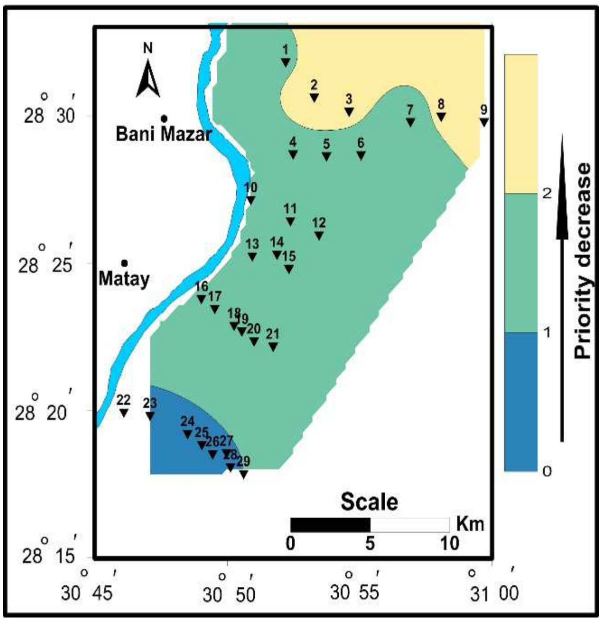

Figure15: Priority map for El-Minia aquifer

CONCLUSION

Based on the obtained geoelectrical results, three water-bearing layers (aquifers) (A3, C4 and D) were detected in the investigated area. The Quaternary deposits represented by the Pleistocene Neonile sediments of sands and gravels with clays and shale lenses (A3) act as the first aquifer, which represents a limited distribution in the considerable area. The second water-bearing layer (C4) corresponds to the water-bearing limestone of Samalut Formation, which lead to the second aquifer, which represents a wide distribution in the s area. The third one (D) corresponds to the water-bearing limestones of El-Minia Formation, which lead to the third aquifer and represents a wide distribution in the concerned area.

According to the priority maps, it can be concluded that, the priorities of groundwater occurrences and their exploitations in the study area generally increase toward the southern parts, especially at Wadi El Saririia area, where El-Minia aquifer occupies the first category and at Wadi El Sheikh Hasan, where the two main aquifers of Samalut and El-Minia facies are well represented.

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