The Use of Earth Resistivity (ER)
and Self-Potential (SP) methods in Groundwater Exploration
in the Area East of Sohag City

Ibrahim, H.A., Bakheit, A.A. and Faheem, S.M.[1]

Geology Department, Faculty of Science, Assiut University,
Assiut, Egypt
Geology Department, Faculty of Science, Sohag Branch, Sohag, Egypt

ABSTRACT. Nineteen vertical electrical soundings (VES) were measured on the surface in the area east of Sohag to provide hydrogeologic information useful in groundwater exploration. These soundings are interpreted using automatic processing and interpretation programs of Schlumberger sounding curves prepared by Zohdy (1989 b). The results of the interpretation indicate the presence of a shallow water-bearing layer especially in the southern part of the area. This layer is diminished toward the east. In certain parts, the low-resistivity material could not be considered as water-bearing bed but it is possibly related to a shale bed dominating the area. The SP and horizontal resistivity measurements taken in certain directions (AA' and CC') show lateral variation of sedimentary facies in these locations.

The application of surface geophysical methods to study groundwater problems is gaining support in the hydrogeological community. Of these methods, the earth resistivity (ER) method have a wide application to problems of groundwater exploration. The self-potential (SP) method occupies secondary importance to groundwater exploration, but it is useful when aligned with ER method.

The area under investigation lies east of Sohag city (Fig. 1). The major problem is the lack of sufficient and safe water supply necessary for present land reclamation, domestic and livestock uses. Therefore, the authors carried out an ER and SP study on the area concerned to investigate possible solutions for the groundwater exploration.
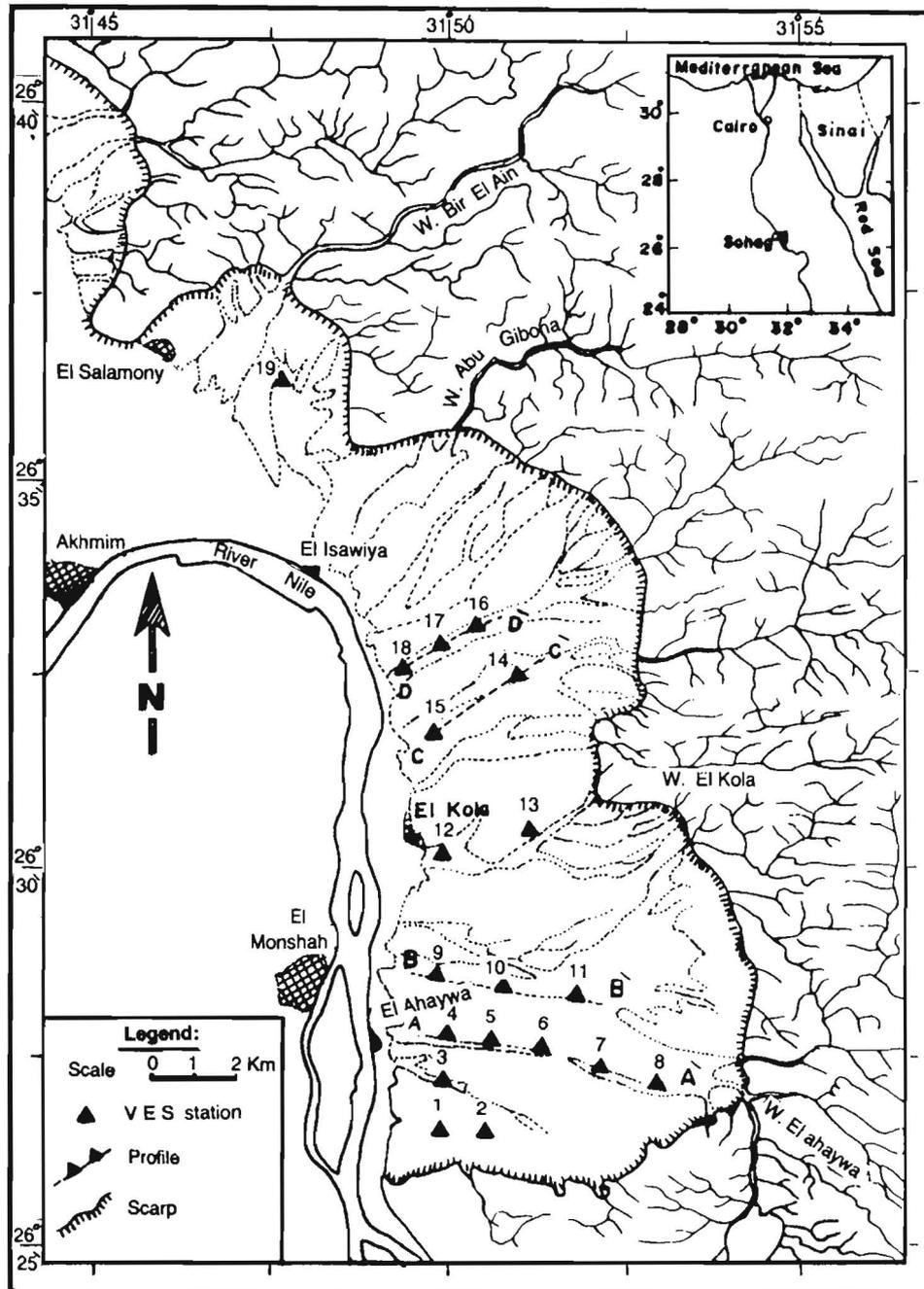
Fig. 1. Location map of the study area

Different geological studies were carried out by different authors on the investigated area and its neighborhood such as Abdel Kireem (1972) and Abdel Rahman (1990) which aimed at obtaining information about the drainage system, the stratigraphy and the structural geology. El-Gamili (1975) carried out a hydrogeological study in Wadi Bir El-Ein area. This study indicates that the aquifer type prevailing in this area is a fracture aquifer which receives direct recharge by rare rain showers. On the other hand Abdel Moneim (1987) carried out a regional hydrogeological study in the Nile Basin in Sohag province.

General Geology

The area under study (Fig. 2) is limited by latitudes 26°25' - 26°46' N and longitudes 31°45' - 31°55' E. It is bounded to the west by the River Nile and to the east by the Eocene limestone plateau. It is characterized by a low relief of elevation ranging between 80-90 m. A major scarp defines the boundary between the lower Eocene limestone plateau and the Post-Eocene sedimentary rocks and extends in NW-SE direction more or less parallel to the course of the River Nile. The lower Eocene plateau bounding the study area to the east is dissected by numerous wadies; W. Bir El-Ain, W. Abu Gilbana, W. El-Kola, and W. El-Ahaywa. Most of these wadies cross the plateau perpendicular to the Nile Valley. The different rock units exposed in the area as mapped by Abdel Rahman (1990) are shown in Figure 2.

Said (1981) described the exposed Post-Eocene sediments of the area east of Sohag city, in Issawia quary, into different sediment types as illustrated in Figure 3a. Unfortunately, there is no available subsurface sections in the study area identifying the subsurface rock units suitable for groundwater accumulation. Therefore, the authors of this work used the section measured in Tahta, to the north of the study area (Fig. 3b) prepared by Said (1981) to assist in the present work.

Hydrogeological Review

The hydrology of the study area is principally governed by the Nile water system , the irrigation canals, and agriculture drains.

Generally, the Cenozoic clastic aquifer has a very wide geographic distribution in the Nile Valley basin and in the adjacent desert wadies. It is mainly composed of gravels, sand, sandstones and clays which is related to Pliocene age overlying the fissured carbonate rocks (Said 1981).
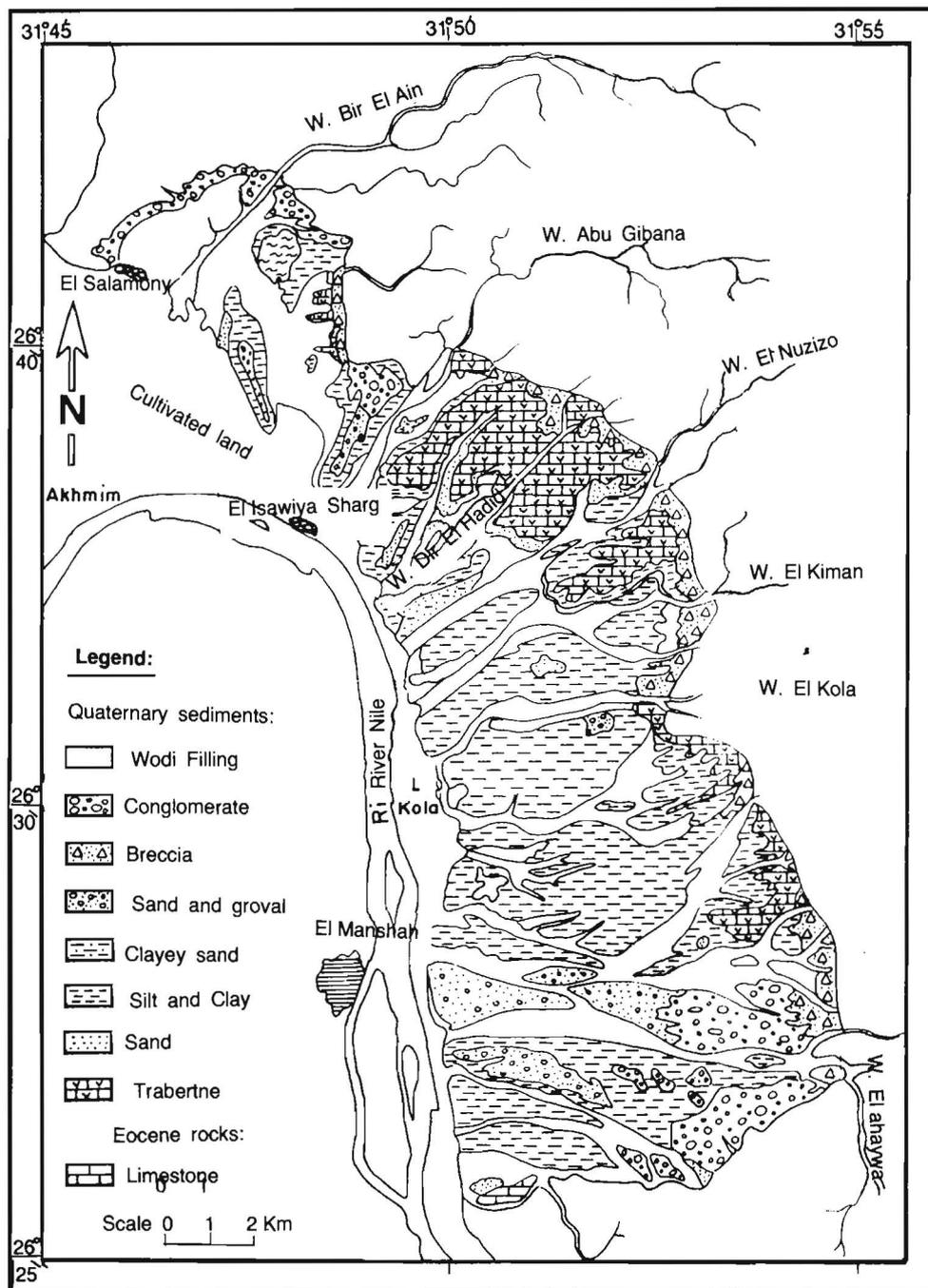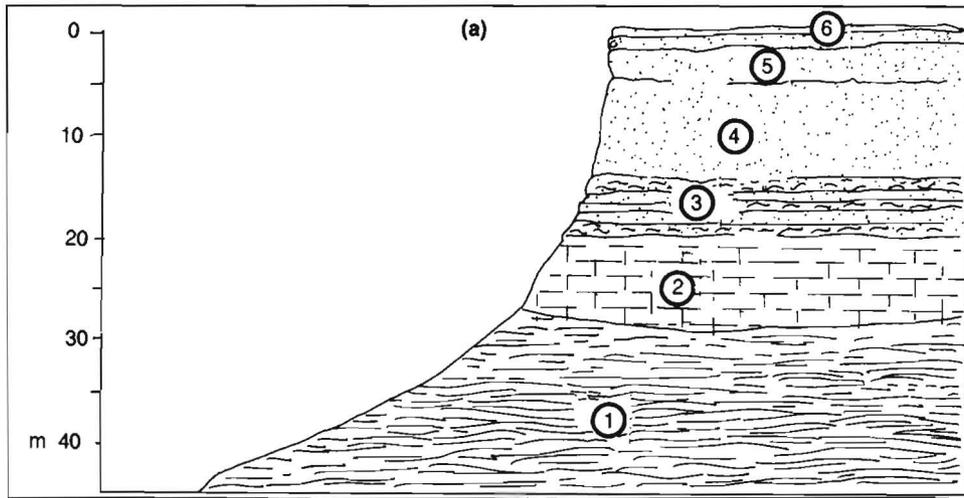
Fig. 2. Geological map of the area east of Sohag (Compiled after Abdel Rahman 1990)

6. Weathered bed of breccia covered with slabs of wind-faceted siliceous limestone.

5. Red breccia made up of angular, siliceous limestone pebbles embedded in a matrix of red-brown muds.

4. Conglomerate made up of siliceous limestone pebbles embedded in a tufaceous matrix.

3. Alternations from marle brown and conglomerate.

2. Travertine, horizontally bedded, hard and with plant remains.

1. Clay grayish brown with gypsum specks in cracks.
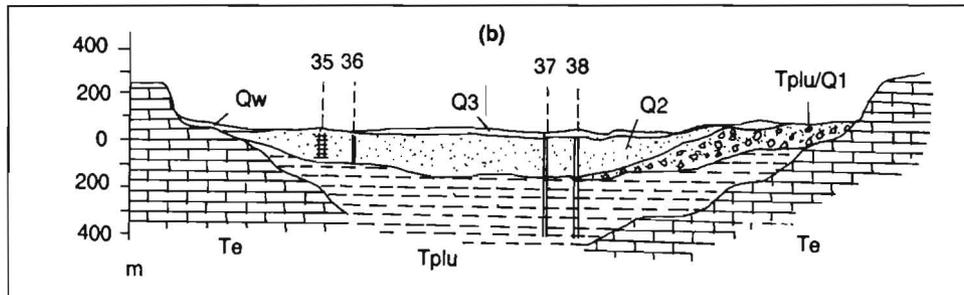
- 35, 36, 37 and 38 well numbers.
- QW subrecent alluvial cover.
- Q3 Neonile sediments.
- Q2 Prenile sediments (Qena Formation)
- Q1 Protoniel sediments (Idfu Formation)
- Tplu Paleonile sediments (Armant and Issawia Formations)
- Te Paleocene and Eocene Limestones.

Fig. 3. a) Section at Issawia quarry, east of Sohag.
b) Cross section in the Nile Valley at Tahta (compiled after Said 1981)

Earth Resistivity (ER) and self-potential (SP) methods

a) Earth Resistivity (ER) method

Two earth resistivity (ER) survey methods are used in the fieldwork. These are: vertical electrical sounding and horizontal resistivity profiling. The objective of electrical sounding as mentioned by different authors, i.e. Zohdy (1974), is to deduce the variation of electrical resistivity with depth below a given line on the earth's surface, and correlate it with the geological knowledge in order to infer the subsurface geology in some detail. Several methods were developed by different authors (e.g. Koefoed 1979, Zohdy 1989 a & b) for the computerized interpretation of vertical electric sounding curves over horizontally stratified media.

The horizontal resistivity profiling technique is normally used for the detection of lateral variations in the electric resistivity of a certain subsurface layer. The technique involves measurements at a grid pattern over the land surface using an electrode array deployed at a fixed spacing.

b) Self-Potential (SP) Method

The SP method, as its name implies, is based upon measuring the natural potential differences which generally exist between any two points on the ground. Different theories are postulated by many authors (*e.g.* Sato and Mooney 1960, Sill 1983 and Kilty 1984) to explain the origin of different types of self potential. The quantitative interpretation of the SP data measured on the surface is more complicated. Therefore, they are only interpreted qualitatively in this study.

Field Procedure

The fieldwork in the study area is conducted using the Italian E 85/A mod controls. The vertical electrical sounding included measuring on 19 stations (Fig. 1). The used Schlumberger array (AB = 600 m) was only sufficient to recognize the shallow aquifer in the area. Unfortunately, the authors of this study could not use AB greater than 600 m, to detect deeper aquifer, because the VES locations and their directions are both governed by topographic accessibility dominating the area such as terraces. The SP and horizontal resistivity profiling are not carried out in all study profiles due to the topographic unsuitability mentioned above. They were measured in steps of equal separation (a = 25, 100 m) along the line of measurements. They are made only along the profiles AA' (a = 25, 100 m) and CC' (a = 100 m).

Results and Discussion

The measured field apparent resistivities in the study area are represented in terms of apparent resistivity sections along the profiles AA', BB',CC' and DD' (Fig. 4). The investigation of these sections reveals the following:

1. The surface dry zone (sand and gravel) in all sections exhibits very high resistivity values (reaching 28,000 ohm .m).
2. The middle zone has moderate values at sections AA' and BB' (100-500 ohm.m), and very low values at sections CC' and DD' (5-10 ohm.m).
3. The third zone is characterized by very high resistivity values at sections AA' and BB' (1000-12 000 ohm.m) and very low values at sections CC' and DD' (10-25 ohm.m).
4. According to the information gathered from the wells drilled by the villagers in the study area, the middle zone at sections AA' and BB' may represent the water-bearing bed in the study area, while at sections CC' and DD' this middle zone together with third one possibly represent the thick shale bed dominated in the area east of Sohag.

The vertical electrical sounding data in the study area are interpreted using the software (Schlumberger sounding data processing and interpretation) prepared by Zohdy in 1989b. Eighteen vertical electrical sounding stations measured in the study area are analyzed in terms of layers of certain true resistivities and well defined depths for the upper and lower surface of the encountered beds.Results of the interpretation of the measured sounding data are presented in Table 1.

Table 1. Results of quantitative interpretation of VES curves in the area east of Sohag city

VES No.	No. of geoelectric layers	True resistivity (ρ_i) of layers in ohm.m.						Thickness (t) of layers in m.				
		ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	t_1	t_2	t_3	t_4	t_5
1	6	9399	2392	88	3	30	∞	1.1	4.0	11.0	35.0	60.0
2	6	28597	9624	547	78	780	∞	1.1	2.5	7.1	40.0	60.0
4	5	9976	691	152	400	∞	-	1.1	6.3	27.0	40.0	-
5	5	19433	506	171	301	∞	-	1.0	3.5	26.0	36.0	-
6	6	21649	592	180	474	1270	∞	3.5	7.5	12.8	27.5	59.0
7	5	3	67	490	2052	∞	-	1.1	2.2	7.3	62.0	-
8	6	47160	2092	510	1750	23880	∞	1.0	3.6	10.0	16.0	68.0
9	4	5038	303	140	∞	-	-	2.3	8.5	63.0	-	-
10	6	22881	910	158	710	4568	∞	1.6	3.5	11.0	18.7	75.5
11	6	23926	380	2997	846	1128	∞	1.5	1.7	18.3	24.7	53.2
12	5	559	50	0.5	62	∞	-	1.1	1.3	49.0	49.0	-
13	5	18913	3270	178	394	∞	-	1.0	1.1	44.0	53.2	-
14	5	4178	1847	130	2	∞	-	1.6	2.0	43.0	94.0	-
15	5	23102	2333	149	1.5	∞	-	2.2	2.5	5.5	137.0	-
16	5	14371	472	147	0.4	∞	-	2.2	4.6	3.2	137.0	-
17	5	3293	588	192	2.4	∞	-	1.1	1.3	5.1	103.0	-
18	5	606	400	143	3.7	∞	-	1.0	2.1	3.6	93.0	-
19	5	60	220	166	3.3	∞	-	2.1	2.3	5.1	55.6	-

* **Remark:** VES3 could not be interpreted due to its distortion.

Two examples, each one showing the digitized curve and interpretation of the sounding (Fig. 5), are selected for illustration in this work. These are the sounding No. 13 and 19. Electrical sounding No. 13 (Fig. 5a) is interpreted in 15 sublayers grouped into 5 layers, while No. 19 (Fig. 5b) is analyzed in 14 sublayers and also grouped into 5 layers.
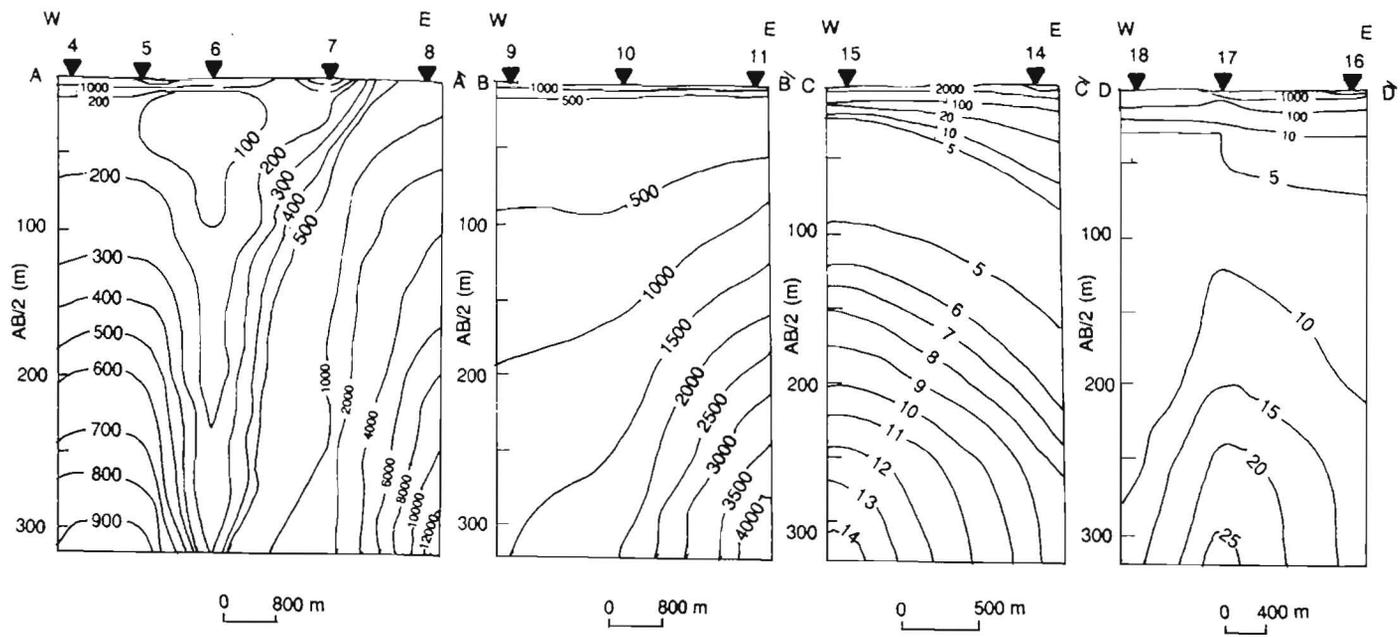
Fig. 4: Apparent resistivity sections along the study profiles.

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Four subsurface cross-sections are initially constructed (Fig. 6) using the interpreted data presented in Table 1. Along sections AA' and CC', SP and horizontal resistivity profiling were made. The inspection of these sections shows the following:

1. Dry surface zone with very high resistivity material (> 20,000 ohm.m) composed mainly of sand and gravel.

2. Wet major zone (140-180 ohm.m) recognized only in the area which includes the cross-sections AA' and BB'. This zone in sections CC' and DD' may be divided into two wet sub-zones; the upper (130-192 ohm.m) and the lower (0.4-3.7 ohm.m). It is important to mention here that the top of the major wet zone in cross-sections AA' and BB' and also the top of the upper sub-zone in cross-sections CC' and DD' may represent the water table. The lower sub-zone in sections CC' and DD' corresponds possibly to a thick shale bed distributed all over the area.

3. Generally, the third zone in the whole area is dominated by very high-resistivity material which may represent the substratum.

4. The qualitative interpretation of the SP values measured along the profiles AA' and CC' shows variation from part to another (-200 to +200 mv). Generally, there is some correlation between the SP profiles (a = 25 and 100 m) measured along the profile AA' (Fig. 6). Such correlation possibly reflects some regularity in the distribution of the sedimentary facies by depth.

5. The SP and horizontal resistivity profiling measurements made along profiles AA' and CC' may reflect a strong lateral variation of sedimentary facies in the area investigated.

Conclusion

In the present study the authors applied the electric resistivity method (the most commonly applied geophysical tool for groundwater exploration) in the area east of Sohag city. 19 vertical electrical sounding stations were measured in different locations of the area. The sounding data are analyzed using the software prepared by Zohdy (1989b). The results of the interpreted sounding curves provided information on the occurrence of a major shallow aquifer underlying the southern sector of the area. Low-resistivity materials in certain parts could not be interpreted as water-bearing materials but they are possibly caused by a thick shale bed found along the whole area east of Sohag.
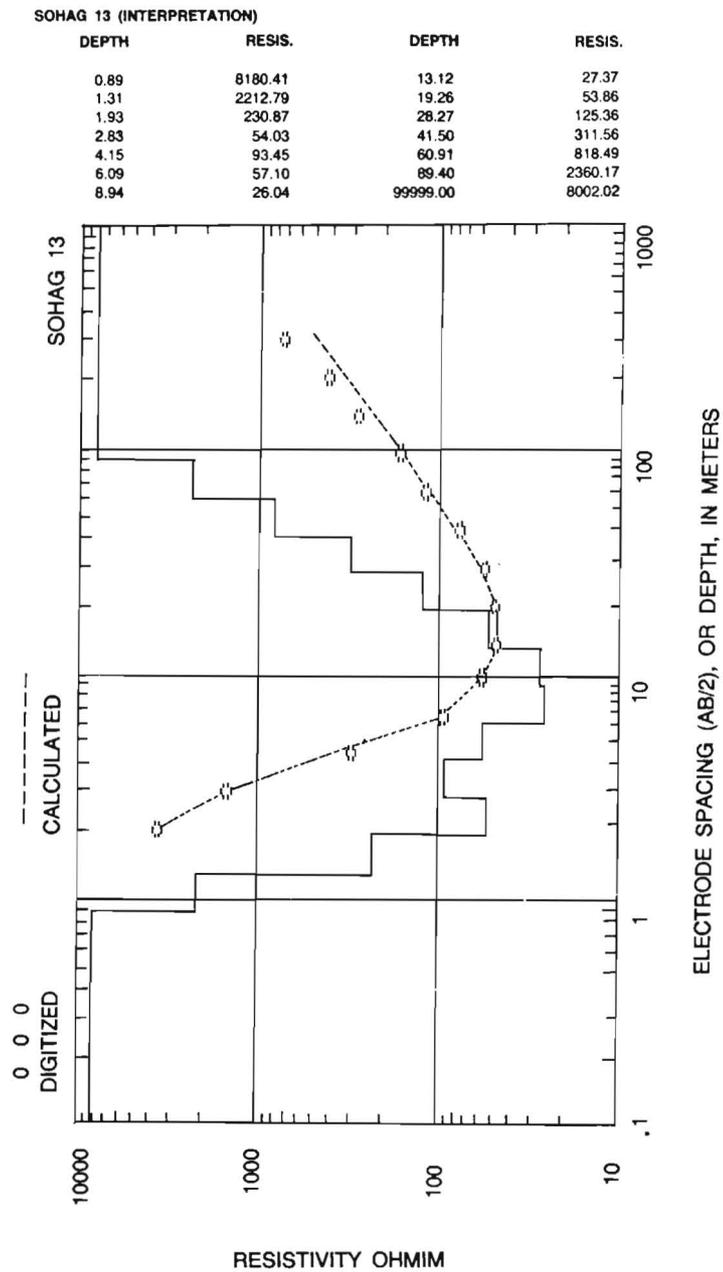
SOHAG 13 (INTERPRETATION)

DEPTH	RESIS.	DEPTH	RESIS.
0.89	8180.41	13.12	27.37
1.31	2212.79	19.26	53.86
1.93	230.87	28.27	125.36
2.83	54.03	41.50	311.56
4.15	93.45	60.91	818.49
6.09	57.10	89.40	2360.17
8.94	26.04	99999.00	8002.02

Fig. 5. Interpretation of VES stations No. 13 and 19

SOHAG 19 (INTERPRETATION)

DEPTH	RESIS.	DEPTH	RESIS.
·0.65	61.08	9.57	60.92
0.96	85.92	14.04	9.04
1.40	121.88	20.61	3.12
2.06	166.40	30.25	3.31
3.03	208.73	44.40	4.50
4.44	222.03	65.17	6.31
6.52	167.56	99999.00	8.45

Fig. 5. Interpretation of VES stations No. 13 and 19
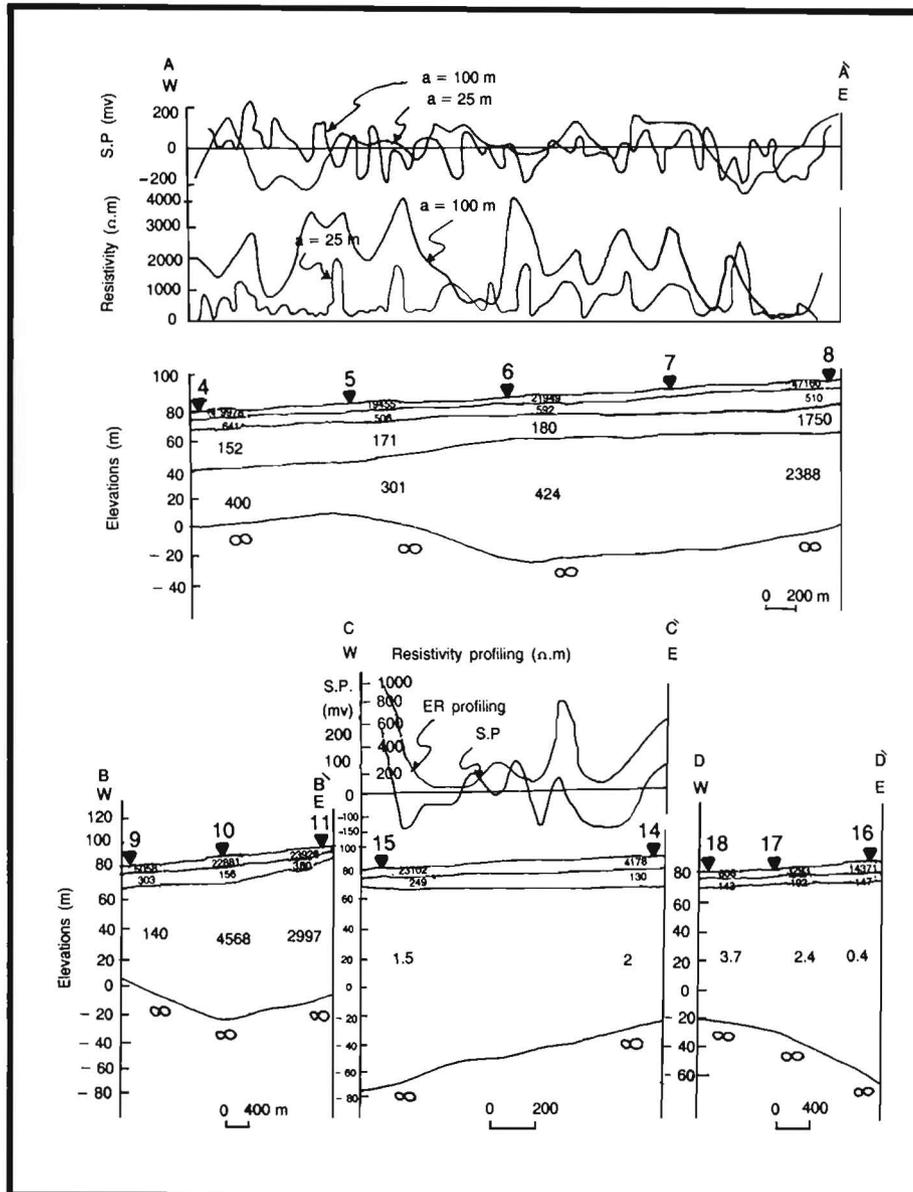
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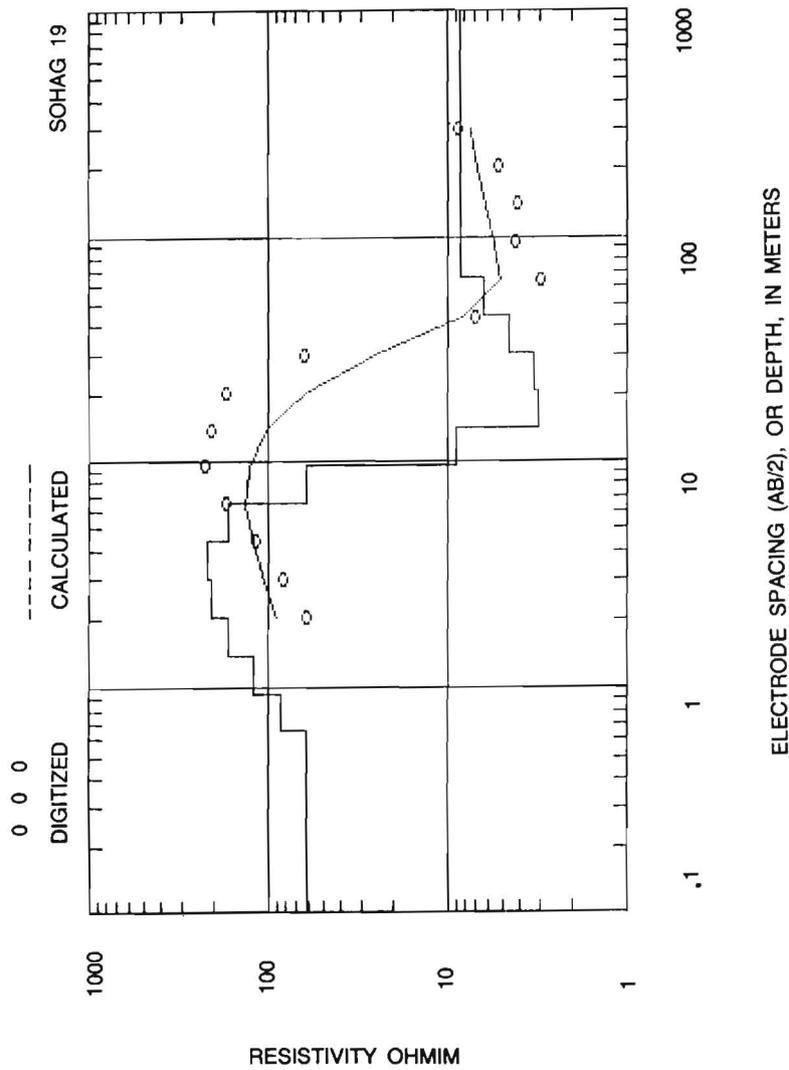
Fig. 6. Geoelectric sections along the study profiles
with SP and horizontal resistivity profiling along AA' and CC'

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دراسة المقاومة الأرضية والجهد الذاتي واستخدامها في الكشف عن مخزون الماء الجوفي في المنطقة الواقعة شرق مدينة سوهاج، مصر

حمزه أحمد إبراهيم و أبو ضيف عبد العال بخيت و صبحي محمد فهيم[1]

قسم الجيولوجيا – كلية العلوم – جامعة أسيوط – أسيوط – مصر

قسم الجيولوجيا ـ كلية العلوم ـ جامعة أسيوط ـ فرع سوهاج ـ مصر[1]

تقع منطقة الدراسة شرق مدينة سوهاج، ويحيطها من الغرب مستوى فيضان نهر النيل ومن الشرق هضبة الحجر الجيري التابع لعصر الأيوسين. يغطي سطح منطقة الدراسة رواسب الرمال والحصى ذو الأحجام المختلفة وينتشر بها الكثير من التلال الرملية التي قد أعاقت توزيع انتشار الجسات بانتظام.

تهدف الدراسة الحالية الى التعرف على الخصائص الجيوكهربائية للطبقات غير العميقة بالمنطقة ومدى امكانية وجود مخزون مياه جوفية بها، وبالتالي فقد تم قياس تسعة عشرة جسة كهربائية بالاضافة الى قياس المقاومة الكهربائية والجهد الذاتي على امتداد بعض البروفيلات (اثنان فقط).

وفحص الجسات الرأسية المقاسة بالمنطقة أوضح أنها تقابل عدد من الطبقات الجيوكهربائية. وقد تم رسم أربعة قطاعات للمقاومة النوعية الظاهرية لتوضيح التغير الجانبي والرأسي في قيم هذه المقاومات الذي يعكس الاختلاف في تركيب هذه الطبقات بالمنطقة.

وقد تم تفسير جميع الجسات المقاسة كمياً بتطبيق برنامج زهدي (١٩٨٩ ب) والتي تم الحصول منها على نتائج تمثل عدد الطبقات الجيوكهربائية عند كل جسة بالاضافة الى سمك وقيمة المقاومة النوعية الحقيقية لكل طبقة. وقد تم رسم

أربعة قطاعات في اتجاهات مختلفة لتتبع الخصائص الكهربائية للطبقات التي تم التعرف عليها والتي أوضحت أيضاً اختلاف سمك وعمق هذه الطبقات من مكان الى آخر. وعموماً أشارت نتائج هذه الدراسة الى الآتي:

١ – وجود طبقة سطحية ذات مقاومة كهربائية عالية (< ٢٠,٠٠٠ أوم متر) وتتكون أساساً من رواسب الرمل والحصى.

٢ – وجود طبقة ذات مقاومة منخفضة (١٤٠ – ١٨٠ أوم متر)، يعتقد أن هذه الطبقة حاملة للمياه باستثناء بعض الأماكن التي تتميز بمقاومة كهربائية منخفضة جداً يعتقد أنها ناتجة من وجود عدسات من الطفله تكثر بها الاملاح.

٣ – النطاق السفلي يتميز بمقاومة عالية جداً، ويعتقد أنه يميز طبقة ذات مقاومة كبيرة (Substratum).

٤ – التنوع الكبير في قيم المقاومة النوعية وقيم الجهد الذاتي (والتي تمت عند كل ٢٥، ١٠٠ متر في اتجاهين فقط)يعكس مدى التغير في سحنه الترسيب بمنطقة الدراسة.

٥ – تتميز الطبقة الحاملة للمياه (الطبقة ذات المقاومة المنخفضة) بعمق قليل، وعموماً يختفي هذا الخزان ناحية الشرق.