Electrical Resistivity Survey in Daibega Plain, Southwest Erbil City – Iraqi Kurdistan Region

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Abstract: Vertical Electrical Soundings (VES) with Schlumberger configuration were conducted in Daibega area (Southwest Erbil City – Iraqi Kurdistan Region). The area is a plain occupying a broad syncline. Obtaining some aquifer parameters, locating favorable groundwater zones, water depth and water types in the area were the aims of this study. For those purposes 26 VES's with 800m current electrode separation were conducted within the watershed area. Interpreted VES data were correlated with some existed borehole columns. A present iso-salinity map of the area was used to obtain the resistivity values of the aquifer water and correlated with resistivity values of aquifer rocks. An iso- depth map for the estimated water table also was constructed. Based on VES interpretations integrated with the previously present data the study showed mostly poor zones of fresh waters. Depth of water table is in the range of 50m in the central parts of the area increasing towards north and south reaching about 80 m. [New York Science Journal. 2008;1(3):20-37]. (ISSN: 1554-0200).

Keywords: Electrical Resistivity Survey; Daibega Plain; Southwest Erbil City; Iraqi; Kurdistan

1. Introduction

The rectangle-shape of the northwestern half of the Daibega plain which is tested electrically in this study is situated some 50km southwest of Erbil City covering an area of about 450km^2 (Fig. 1).

Other than rain in winter and spring seasons no surface water supply sources or water projects are present for most of the villages within the plain. The only source is the underground water. A lot of hand-dug and some deep wells have been drilled. Many of them are not suitable for human drinking because of salinity of their water. Salts are mainly because of the gypsum which exists as one of the lithological units of the Lower Fars Formation.

The resistivity method involves measuring the electrical resistivity of earth materials, by introducing an electrical current into the ground and monitoring its developed potential field. In most earth materials, electricity is conducted electrolytically by the interstitial fluid. The resistivity is controlled mostly by porosity, water content and water quality than by the resistivities of the matrix (Ayer, 1989). The main target is the identification of horizontal and vertical variations in lithology (including water type in pores), which lead to clarify the structural picture of the subsurface.

The present data was originally used for the assessment of the groundwater situation in the area under study by the Swedish Qendeel NGO, Erbil. This work was carried out by their permission.

2-Geology

The area according to Numan, 1997 is located within the Zone of "Suspended Basins' of the Quasiplatform forland. This area is equivalent to the so-called "Foot Hills Zone" which belongs to the "Folded Zone" in former literature of the tectonics of Iraq (Buday and Jassim, 1987) (the upper box in Figure-1). This zone is characterized by relatively long double plunging anticlines with broad synclines in-between. They mostly trend in the NW-SE direction. The Daibega plain is a syncline between the two anticlines Avana in the northeast and Qerechugh in the southwest. In the north of the plain a third anticline (Gwair) is present in an en-echelon position (Figs. 1 and 2).

The oldest rock formations present in the area are those which belong to Oligocene age. These rock formations collectively form the core of the Qerechugh Anticline (Fig. 1). This figure also shows a cross section across the plain. Table 1 shows a summary for all exposed formations in the area (cited in Al-Sudany, 2003).

Table 1. Stratigraphic Summery in Daibega area

Formation	Age	Thickness (m)	Description
SheikhAlas, Shurau, Targil, Baba Bajwan, Azkand and Anah	Oligocene	~200m	Different types of limestone (Fossiliferous, Dolomitiic, Chalky or Recrystallized)
Euphrates Formation	L.-M. Miocene	40-45	Dolomitic Limestone
Lower Fars	M. Miocene	123-200	Limestone, Claystone and Gypsum
Upper Fars	U. Miocene	46-141	Sandstone, Clatstone and Siltstone.
Lower Bakhtiari	L.Pliocene	42-200	Sandstone, Clatstone and Siltstone.
Upper Bakhtiari	U. Pliocene	30-50	Conglomerate
Quaternary	Pleistocene-Holocene	~10	Sand, Silt, Clay and Gravel

The studied area ranges topographically from mountainous reaching altitude of 750m.a.s.l. in the Qerechugh series and more than 400m.a.s.l. in the Avana series (Fig. 2) while the plain is in the range of 300m.a.s.l. The central area of the plain is slightly elevated relative to both the northern and southern parts, hence valley courses drain water due to north (Greater Zab River) and south (Smaller Zab River) following dendritic and parallel patterns. Physiographycally the area belongs to the undulated zone of the Iraqi territories.

3-Resistivity Survey and Hydrogeology

Geo-electrical resistivity techniques are popular and successful geophysical exploration for the study of groundwater conditions in the world. The resistivity of materials depends on many factors such as groundwater salinity, saturation, aquifer lithology and porosity (Lashkarippour *et al.*, 2005).

Relationships between aquifer characteristics and electrical parameters of the geoelectrical layers have been studied and reviewed by many authors (Kelly, 1977; Niwas and Singhal, 1981; Onuoha and Mbazi, 1988; Mazac *et al.*, 1985; Mbonu *et al.*, 1991; Huntley, 1986, Lois *et. al.* 2004 and Asfahani, 2006. Some researchers assume that the geology and ground water quality remains fairly constant within the area of interest and the relationships between aquifer and geophysical parameters deduced, are based on this assumption (Niwas and Singhal, 1981; Mbonu *et. al.*, 1991). Mazac *et. al.* (1990) analysed the correlation between aquifer and geoelectrical parameters in both the saturated and unsaturated zones of the aquifers.

Geophysical methods can now contribute substantially towards this initiative and can greatly reduce the number of necessary pumping tests, which are both, expensive and time consuming. The area of Daibega plain was selected as a test area to provide information on the aquifers hydrodynamic characteristics, by means of correlation tests performed between electrical parameters measured by surface geoelectrical soundings and aquifer characteristics obtained from a certain number of boreholes in which lithology is deduced and salinities were measured.

4-Data Acquisition

Electrical resistivity soundings are generally used to determine electrical resistivity variations as a function of depth. The ABEM Terrameter SAS4000 was utilized in data gathering. A total of 26 Vertical Electrical Sounding (VES) were undertaken in 18 villages (Fig. 1) in the Daibega plain, one VES in each site. In four of the villages extra-two points were tested to obtain local shallow subsurface pictures. Six of the VES points were conducted nearby existed boreholes for correlation purposes. The Schlumberger electrode arrangement was used for the measurements. This type of arrangement is widely used in explorations because it is an efficient means of collecting a large number of data points (time effective in terms of fieldwork) and these observations are sensitive to the lateral position and depth characteristics of the resistivity distribution. All spreads of electrodes were designed to be in the NW-SE direction (i.e. parallel to the general structures strike). The maximum current electrode spacing (AB) was 800m. in all sounding points.

The TDS data used in this study were extracted from an iso-salinity map constructed at the beginning of 2001. This map was constructed depending upon the analyses of water in many locations within the Mekhmoor District which Daibega area is occupying the northeastern sector. Among the water wells that Al-

Sudany, 2003 used are the six boreholes which were depended upon in this study for the purpose of correlation with sounding results.

5-Interpretation

The first stage of any interpretation of apparent resistivity sounding curves is to note the curve shape. This can be classified simply for three electrical layers and then combined to describe more complex field curves that may have several more layers (Reynolds, 1997). This step is called qualitative interpretation. Examples of field curves are given in Figure-4.

The visual inspection of the field data showed the presence of twelve types of curves. This large number of types reflects the horizontal variations that characterize the plain (Table 2). The first three layers in all sites are either of the following types; H, K or A. Q-type is not present anywhere in the area. Three sites showed six-layer case. They are located within the two anticlines of Qerachugh and Avana.

Sounding curves were interpreted quantitatively using the IPI2WIN Russian program. More than one iteration were tried to reach the best fit between the field curve and the calculated one. Examples of the results are given in Figure-3. The range of error in all of the interpretations was acceptable restricting between 0.03 and 5 depending upon the field data which were generally of good quality. Final results of the interpretation of all data in the 26 sounding curves are shown in Table-2. Numbers in this table are referring to villages that their names are given in Figure-1.

Table 2: True Resistivity and Depth of Horizons.

VES No.	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	ρ_5	D_1	D_2	D_3	D_4	Curve type
1	26	18	59	2	12			1	5	47	109	HKH
2	130	233	29	12				1	4	12		KA
3	84	291	31	19				2	3.4	89.4		KA
4	215	135	62	34	1			1	10	49	282	AAA
5	76	21	117	21	30	12	1	2	10	50	207	HKHK
6	67	103	13	52	4			4	20	43	202	KHK
7	43	22	100	13	20			1	2	7	54	HKH
8	83	196	16	33	13			1	1.8	7	37	KHK
8A	230	23	84	16				2	4	33		HK
8B	70	15	26	8	17			1	7	8	41	HKH
9	104	1	38	6	12	17	1	1	2	4	127	AHAA
10	65	183	16	9	20			1.5	2.5	17	56	KHA
11	94	29	9	13				1	5	92		AH
11A	34	5	14	6	17			1	1	18	94	HKH
11B	43	17	6	13				2	14	86		AH
12	15	19	9	18	9			3	10	39	116	KHK
13	109	18	10	25				1.5	50	145		AH
14	146	29	5	8				1	3	52		AK
14A	48	36	6	3	10			1	8	43	74	AAH
14B	103	21	2	7	12			1	2	1	135	AHQ
15	79	10	25	13				1	35	95		HK
16	103	85	27	49	19			4	12	63	154	KHK
17	101	26	10	17				1	2.5	106		AK
18	19	3	56	8	52			1.5	3	20	45	HKHK
18A	19	4	68	13	65			1	2	10	19	HKH
18B	52	107	20	54	17			1	1	12	46	KHK

ρ: resistivity (Ω.m.), D: depth to horizon (m)

The following observations could be concluded from this table:

1- A maximum resistivity value of 291 Oh.m. was registered in VES 2 while a minimum of 1 Ω.m. was registered in the deeper parts of VES 4, 5 and 9.
2- Majority of the VES curves showed the presence of five electric horizons (14 points out of 26).
3- Maximum depth of investigation was 282m below surface in VES 4.
4- VES 2 and 3 have the maximum values of resistivity among all. They are located within the boundary of Gwair Anticline.
5- The resistivity value of the uppermost horizon ranged from 15 to 230 Ω.m.

6-Correlation with Existed Wells

Six of the VES points were correlated with six of the nearby existed wells (Figs. 4 and 7). The following observations could be given:

1-Water table depths as interpreted from the resistivity data are consistent with those of the wells to a good extent if we keep in mind that the drawdown is a normal phenomenon in Erbil and surrounding areas due to the drought conditions which the whole area suffered cyclically during the last ten years. Resistivity measurements in this study were taken about four years after the date of obtaining the well columns in 2001 (Al-Sudany, 2003). From the resistivity data the water table depth is deeper in all six localities than those of wells. This difference is attributed to the above-mentioned drawdown.

2-Resistivity values of the aquifer rocks range between 8 and 34 Ω.m. The minimal values indicate salty water contents.

3-The aeration zone in the wells is composed of mixture of clay, silt and sand with variable ratios. Their resistivity value ranges from 5 to 62 Ω.m. depending on that ratio and salty materials content. The electric properties of the aeration zone are subject to seasonal or sporadic changes which depend mainly on the amount of precipitation and on the temperature and barometric conditions (Ogilvy *et al*., 1980).

7-Iso-Prameter Maps

7.1-Iso-Resistivity Map of the Aquifer Rocks

The map of the iso-resistivity values in the Daibega plain (Fig. 5) shows two main anomalous zones. The high values are located in the area north of Mekhmoor town occupying the western central parts while the lower values are occupying the central northern parts. According to this map the first zone is likely to be better for obtaining waters of lower values of salts relative to other zones of the studied area.

7.2- Iso-Resistivity Map of the Aquifer Water

Aquifer water conductivities (inverse of resistivity) of the Daibega area were derived depending upon the values of Total Dissolved Salts (TDS) aforementioned by multiplying them by (1.4). This conversion factor was used to make the resistivities in units of Ω.m. (www.Geo-Hydrology.com)

This conversion factor is often used when actual factor of a certain area is not known. Table (3) shows conductivity and resistivity values as well as some other aquifer factors.

Table 3. Some Aquifer Parameters.

VES No.	$\rho_{aquifer.rocks}$	W.T.D.	T	TDS	σ	ρ_{water}
1	7	47	62	500	700	0.149
2	12	12		900	1260	0.083
3	19	89		1400	1960	0.053
4	34	49	23	500	700	0.149
5	21	50	157	4200	5880	0.0177
6	13	20	23	3750	5250	0.0198
7	20	45		5000	7000	0.0148
8	13	37		3400	4760	0.022
9	12	127		3400	4760	0.022
10	20	56		4000	5600	0.0186
11	13	92		2700	3780	0.028
12	18	39	75	1280	1400	0.074
13	10	50	95	450	630	0.165

14	5	52		1400	1960	0.053
15	25	95		4500	6300	0.017
16	49	63	83	3000	4200	0.025
17	17	102		1800	2520	0.041
18	8	20		500	700	0.149

ρ : resistivity (Ω.m.), σ: conductivity (μs/cm), T: thickness (m),
TDS: Total Dissolved Salts (ppm), W.T.D.: water table depth (m).

Figure 6 shows the map of iso-conductivity values of the area. This map indicates a sharp subdivision between a low-conductivity values zone in the northwestern part and a high values zone in the southeastern part. The former part is being related geologically to the northeastern plunges of both the Qerachugh and Avana Anticlines and the Gwair Anticline. This geological subdivision is reflected as change in conductivity distribution which is also affected by the topographic change along the same direction (see also Figure-2)

The map of the iso-resistivity of the aquifer water (Fig. 7) on the other hand shows three zones of high resistivity water (Zones A, B and C in figure 7). The first one (A) occupies the area of high resistivity aquifer rocks mentioned above in figure (6) north of the Mekhmoor town. The coincidence of these two types of data in the same zone gives a clue that this zone is actually the better from the water type point of view in the studied area. Geologically this zone is located on the northeastern limb of the Qerachugh Anticline. This limb is steeper than the northeastern limb of the syncline (southwestern limb of Avana Anticline) (Fig. 1). Because of the high dip it seems that the depth of investigation of the resistivity method used in this study (VES 5, 6, 8 and 9) as well as the water from which the TDS tests were taken are within the uppermost rock formations. These are the Upper Fars, Lower Bakhtiari, Upper Bakhtiari and Quaternary deposits. They collectively overlie the main source of salts in the area which comes from the Lower Fars Formation.

Zones B and C on the other hand have almost the same geological conditions. The first is located on the southeastern Gwair Anticlinal plunge near to the narrow syncline between Gwair and Qerachugh Anticlines while the second occupies the northwestern plunge area of Avan Anticline.

The southeastern parts on the other side show decreasing of resistivity values towards southeast. This indicates the increase in salts and coinciding with the decrease in rock resistivities (Fig. 5) and increasing conductivities (Fig. 6).

7.3- Iso-Depth Map of the Water Table

The depth to water map in Figure-8 shows that the central parts of the north and south show higher depths (more than 50m) for water table than the central area (less than 50m). The six VES points that were carried out near water wells show good consistency in results. Again a subdivision between the northwest parts of the whole area with the southeastern part can be noted. This can be related as mentioned before with the surface topography which in turn may reflect structural features.

8-Geo-electric Sections

These sections are the vertical distribution of resistivities within a particular volume of the earth. The section consists of a sequence of uniform horizontal (or slightly inclined) layers (horizons). The layer's true resistivity is noted on each one for each VES sounding. After that several sections for VES points which are located on a certain traverse can be linked together to show a cross sectional view of the traverse. Each layer (horizon) in a geo-electrical section my completely be characterized by its thickness and true resistivity.

1-The two geo-electric sections A and B in Figure-9 were constructed between VES's 14, 15 and 16 and VES's 6, 7 and 17. They show the subsurface configuration along lines cutting the Avana structure in the E-W direction (Fig. 9A). and cutting the plain in-between the two anticlines (Fig.9B), in the NE-SW direction. Though the number of VES points is not so adequate to make a full interpretation, some conclusions could be derived however.

In the first section more than one inter-fingering within horizons can be observed. Below water table, the aquifer seems to be containing fresh water up-slope (towards east) while being more salty down-slope. Water salinity also increases downward deeper in the aquifer. The aquifer is likely to be confined since it is covered by a clayey horizon which diminishes eastward.

In the second section (Fig. 9B) the general shape of the syncline can be noted. Two main horizons are present other than the uppermost horizon which represents Quaternary deposits. A clayey horizon increasing in thickness towards northeast is covering the aquifer again making it confined. The boundary between fresh and saline waters is roughly marked.

2-Four other local geo-electric sections were constructed in four localities. These are in the villages [Malik Agha (VES's 8, 8A and 8B), Chghlok (VES's 11, 11A and 11B), Said Obied (VES's (14, 14A and 14B) and Chilhaweza (VES's 18, 18A and 18B) (Figs. 10A and B and 11 A and B respectively).

Three of these sections show the presence of salty water (Fig. 10A and B and Fig. 11A) while the fourth section indicates the presence of fresh water in the aquifer (Fig. 11B). This latter section represents the locality 18 (Chilhaweza village) which is situated on the crest of the Avana Anticline. Figures 10B, 11A and 11B show that the aquifer is overlain by clayey horizons. The section in figure 10A is constructed depending upon some cropping out rocks which belong to Lower Fars and Upper Fars Formations.

9-Conclusions

Daibega simple hummocky plain was surveyed using the resistivity method by taking (26) VES points. Data was interpreted qualitatively and quantitatively. The results were integrated with some previous hydrogeological data. The following points are concluded:

1- Twelve different sounding curve types were obtained representing four to six horizons (Table-2).

2- Estimated water table depths are in acceptable consistency with those obtained from the water wells (Figs. 4 and 8). This depth is less than 50m in the central parts increasing towards north and south to reach about 80m.

3- The high resistivity values of aquifer rocks are located in the area north of Mekhmoor town occupying the central parts while the lower values are occupying the central northern parts (Fig. 5).

4- Aquifer water resistivities are distributed in three zones of high values. They occupy the northwestern areas while values decrease in the southeastern areas (Fig. 6).

5- Six geo-electrical sections were constructed. Two of them cut the Daibega plain and the Avana Anticline respectively while the other four are local in four different sites (Figs. 10 and 11). The (regional) sections show an invasion of salty water in the down-slope direction.

Among the four local sections the locality 18 (Chilhaweza village) gives indication for the presence of fresh water. This site is located on the crest of Avana structure.

10-Acknowledgments

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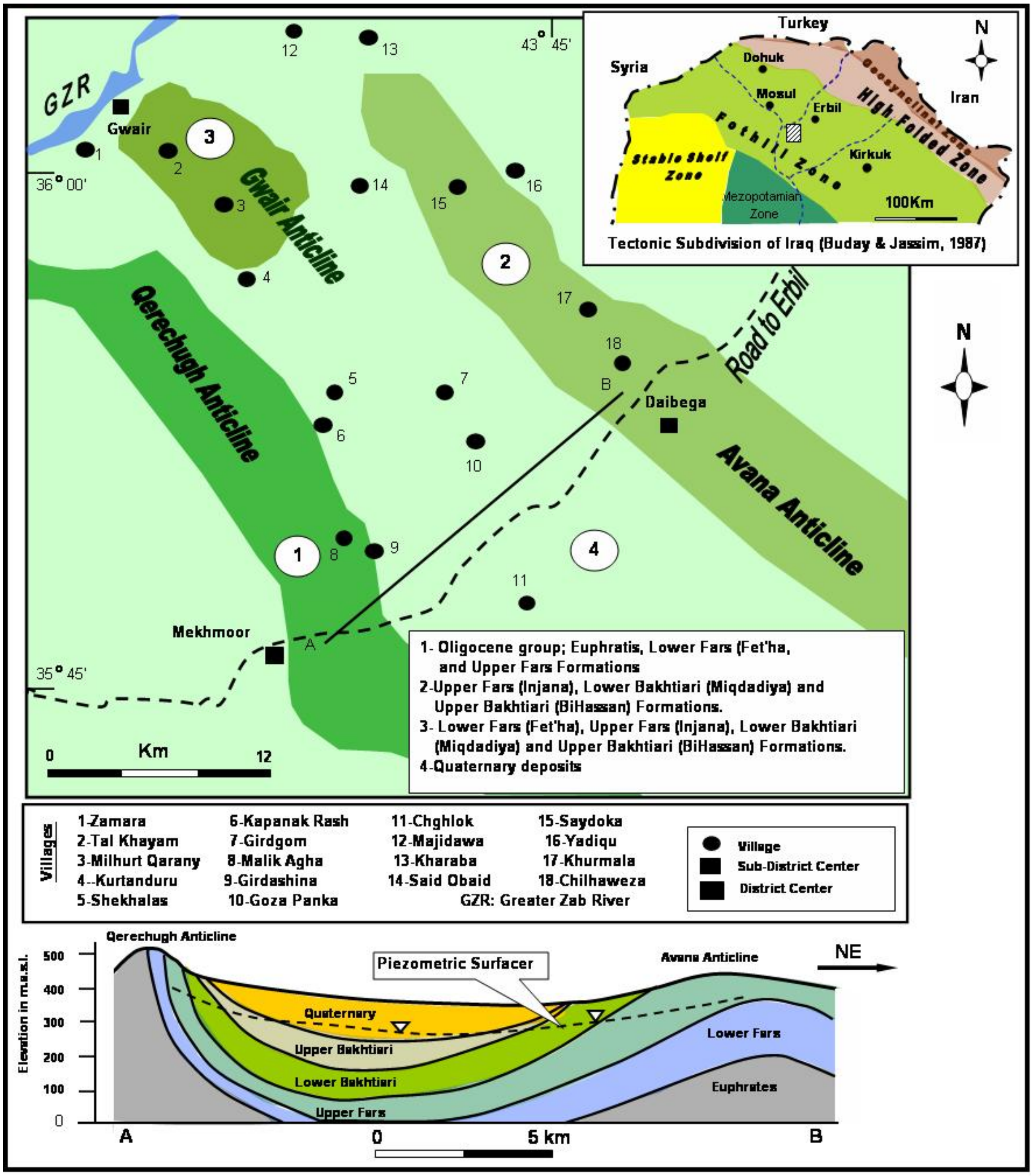

Fig. 1: Geological Map of Daibega Area, Cross Section Along the Plain (Cited in Sudany, 2003) **and Tectonic Map of Iraq Showing the Location of Daibega Area**

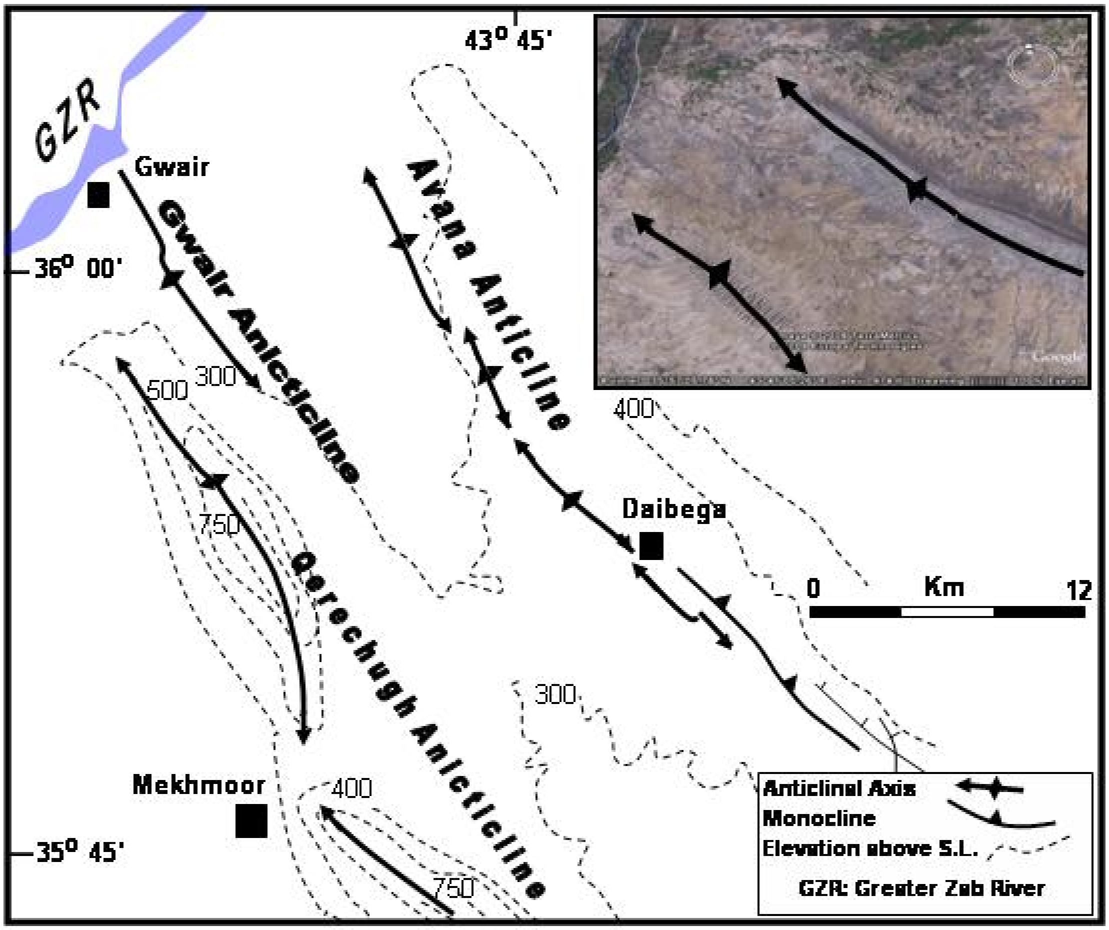

Fig. 2: Tectonic Map of Daibega Area

(Cited in Al-Sudany, 2003)

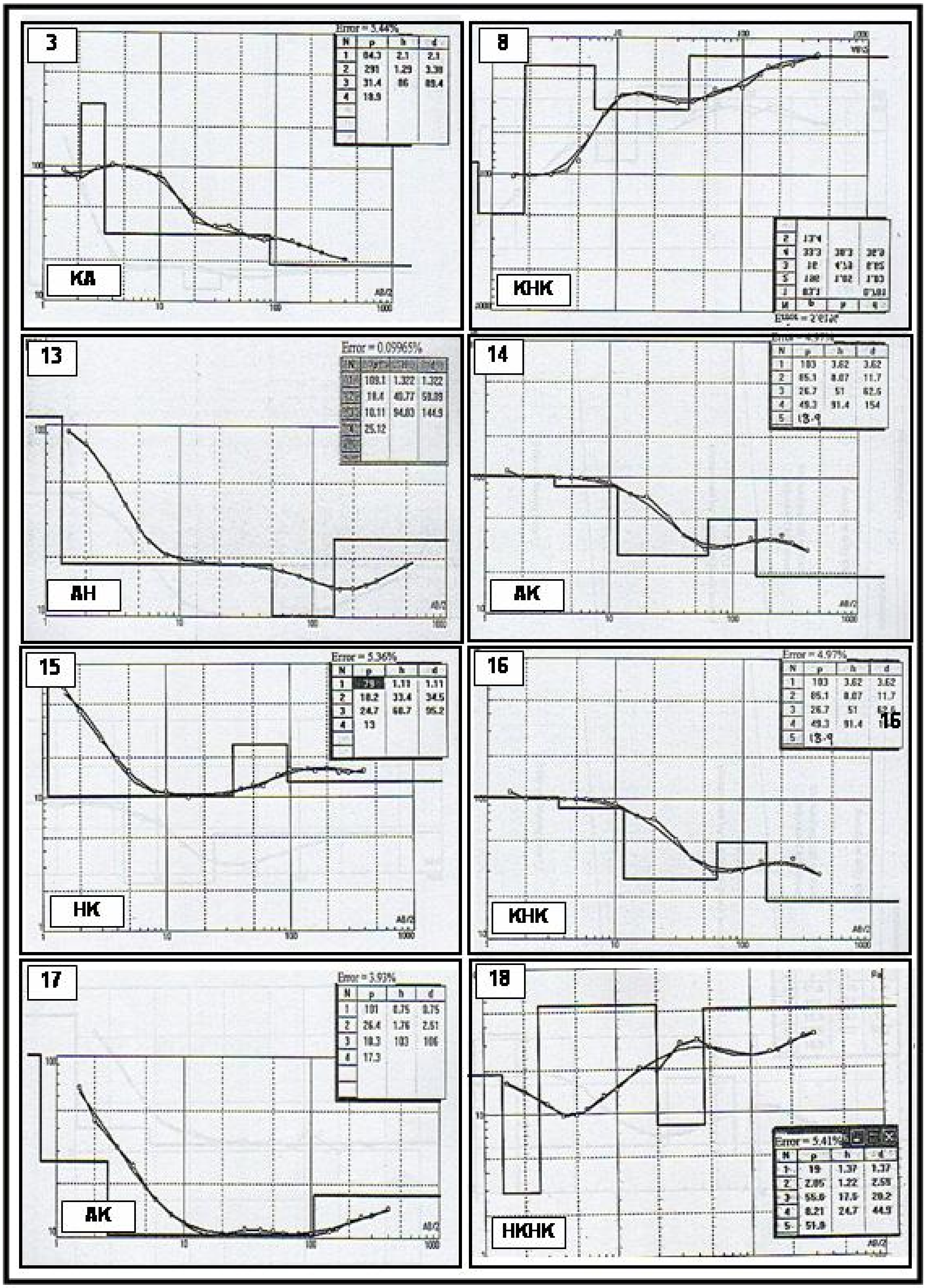

Fig. 3: Some Examples of Field Curves and their Interpretation Results

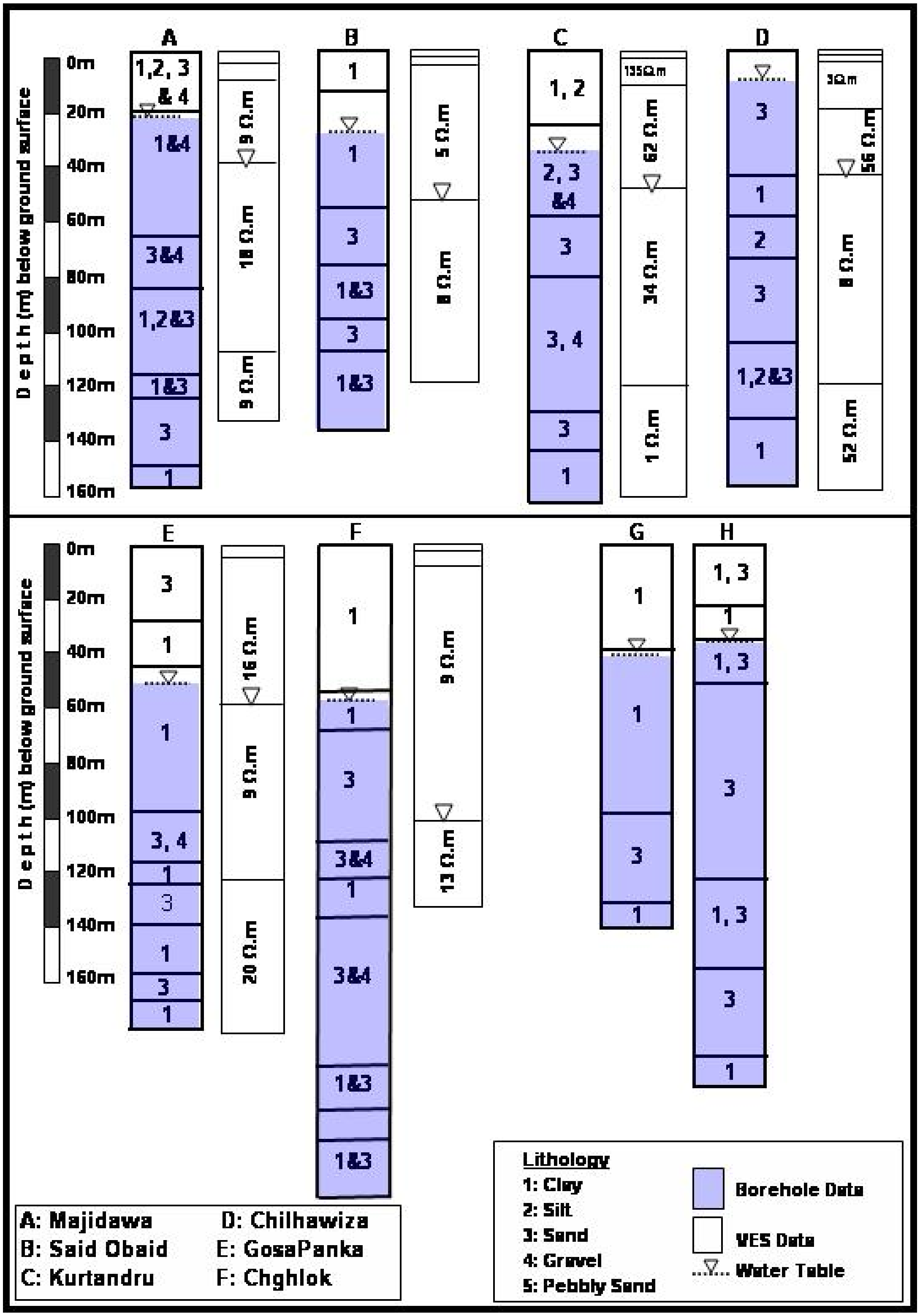

Fig. 4: Borehole Stratigraphic Columns as Correlated with VES Results.

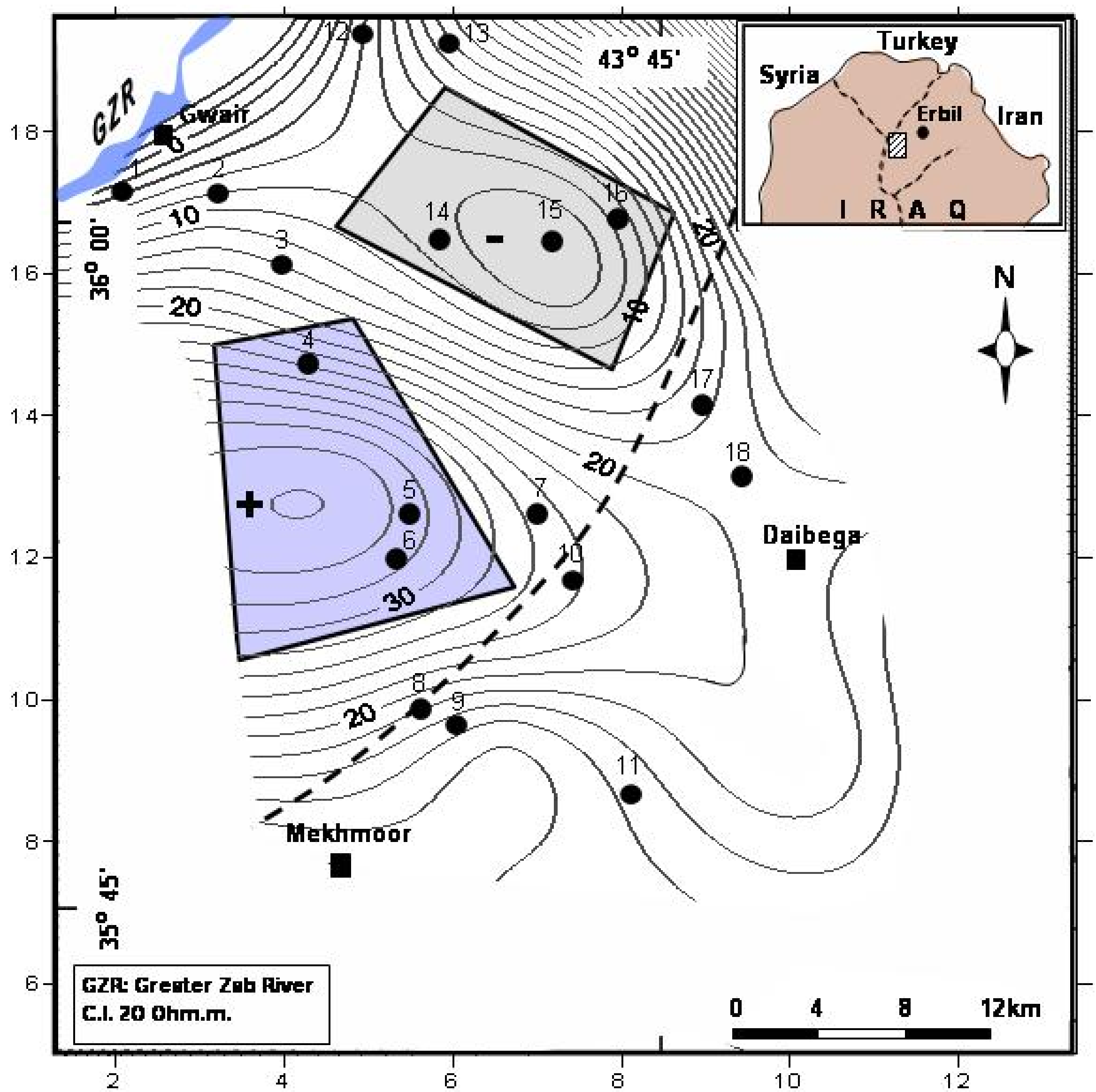

Fig. 5: Iso-Resistivity Map of the Aquifer Rocks.

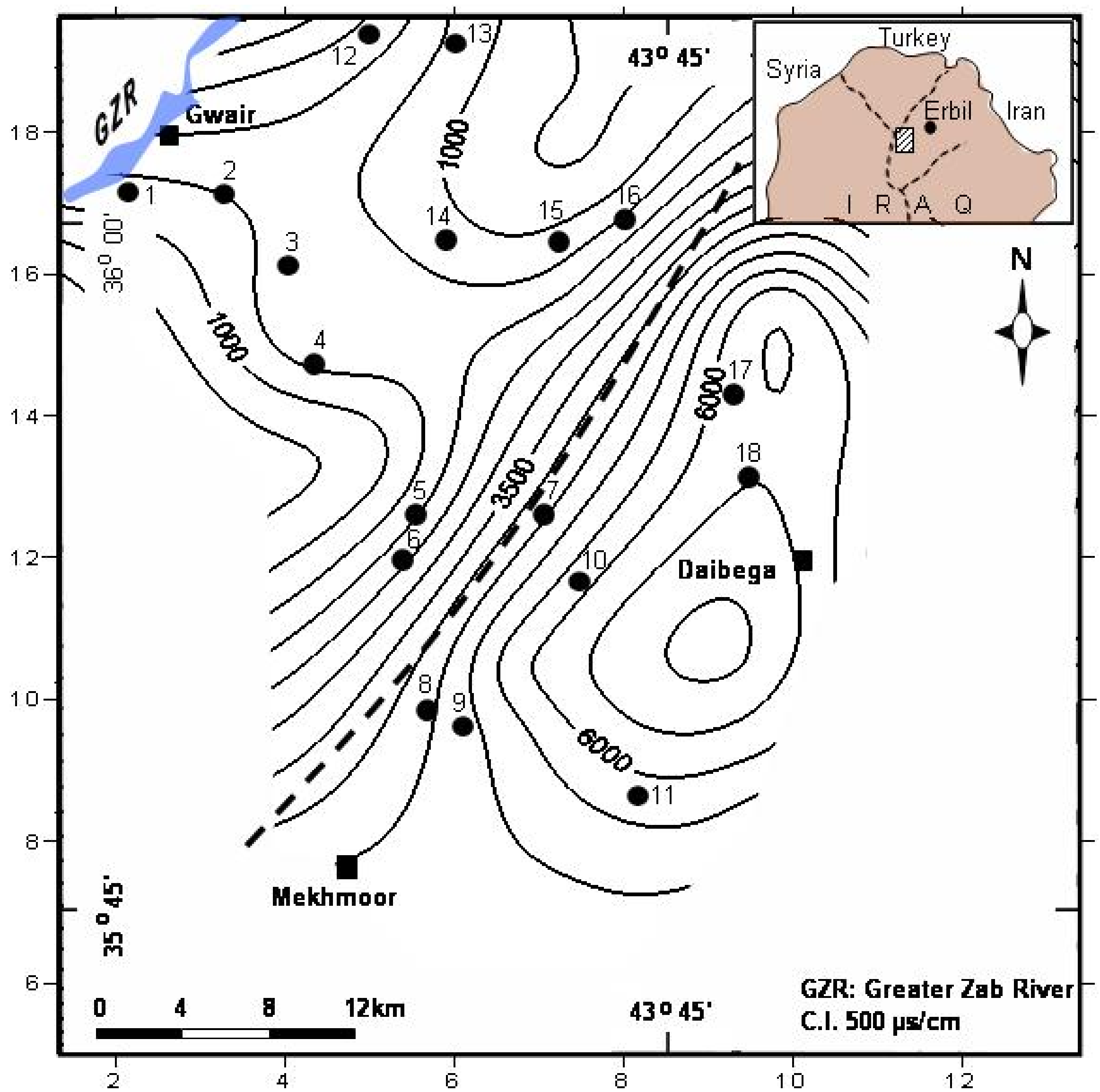

Fig. 6: Iso-conductivity map

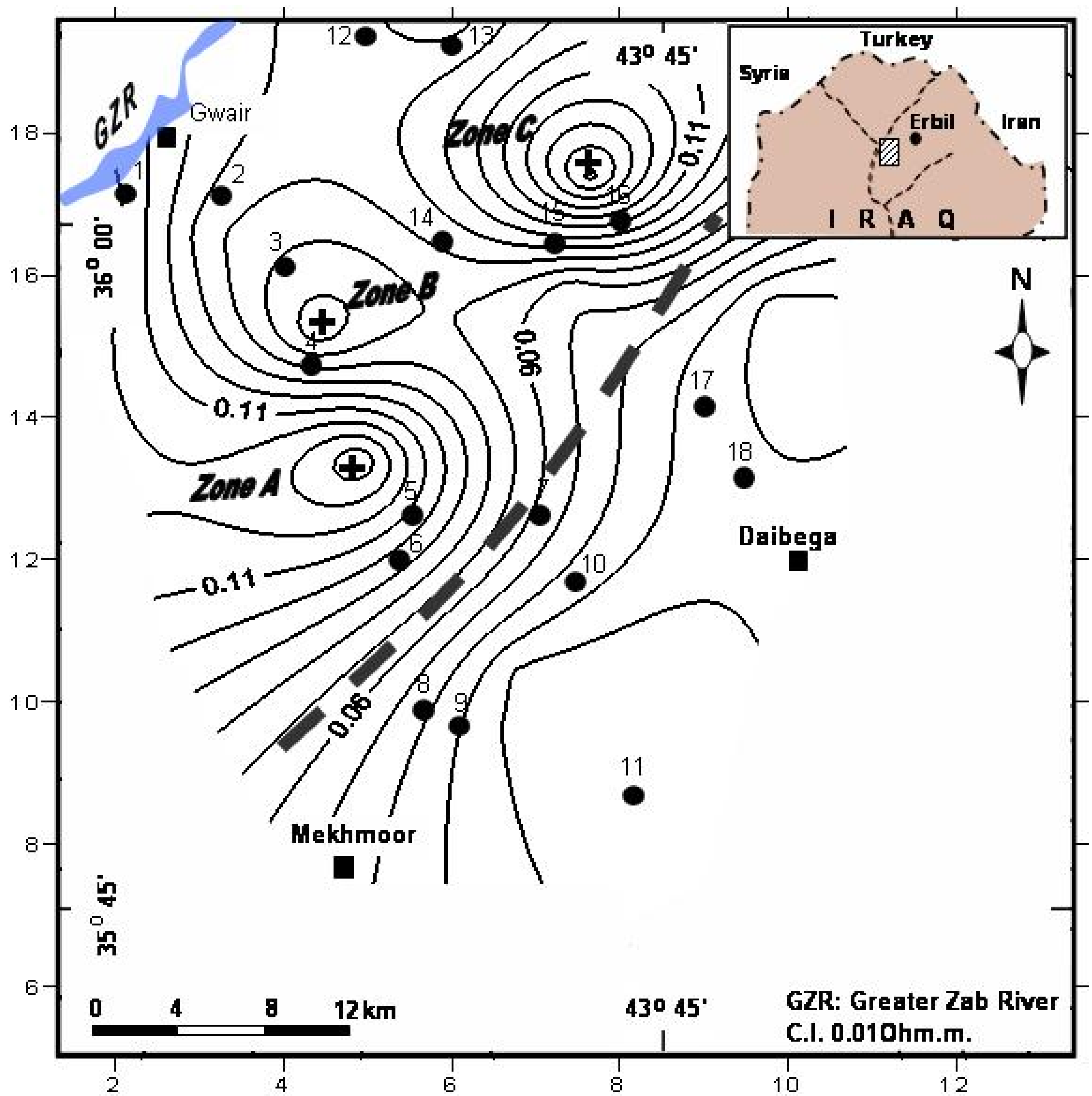

Fig. 7: Iso-Resistivity Map of the aquifer water

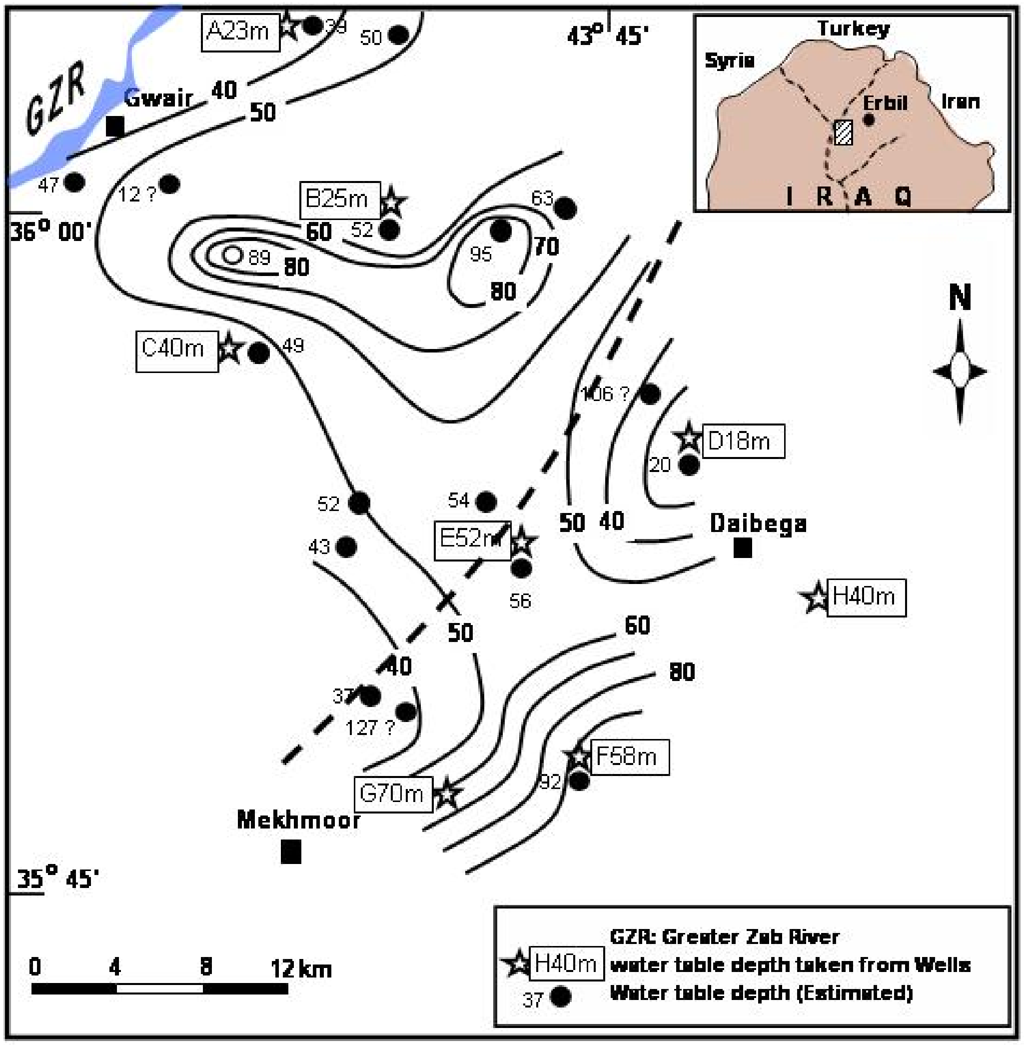

Fig. 8: Water Table Depth Map Estimated from Resistivity Data

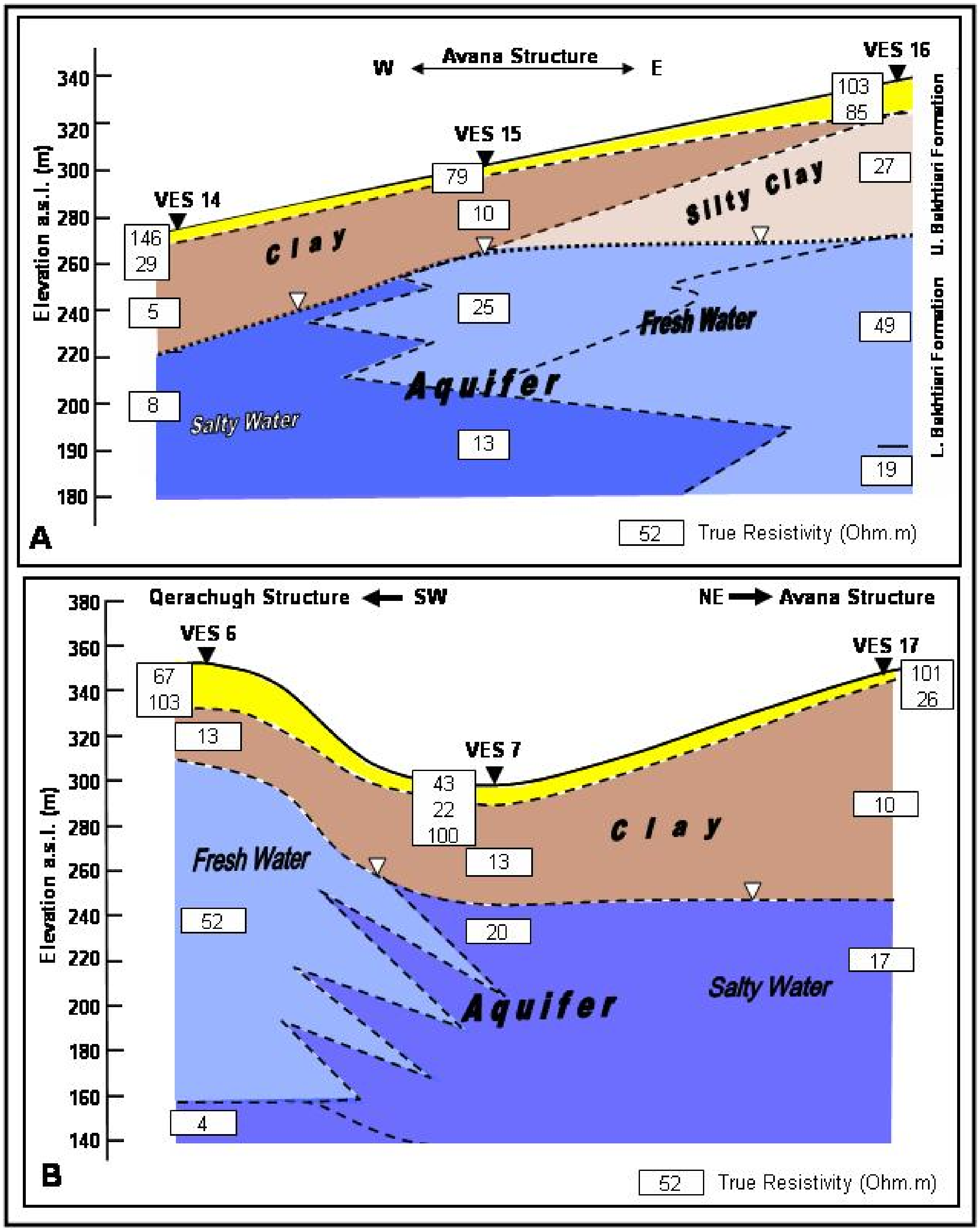

Fig. 9: Geo-electric Sections Across the Avana Structure (A) and the Daibega Plain (B).

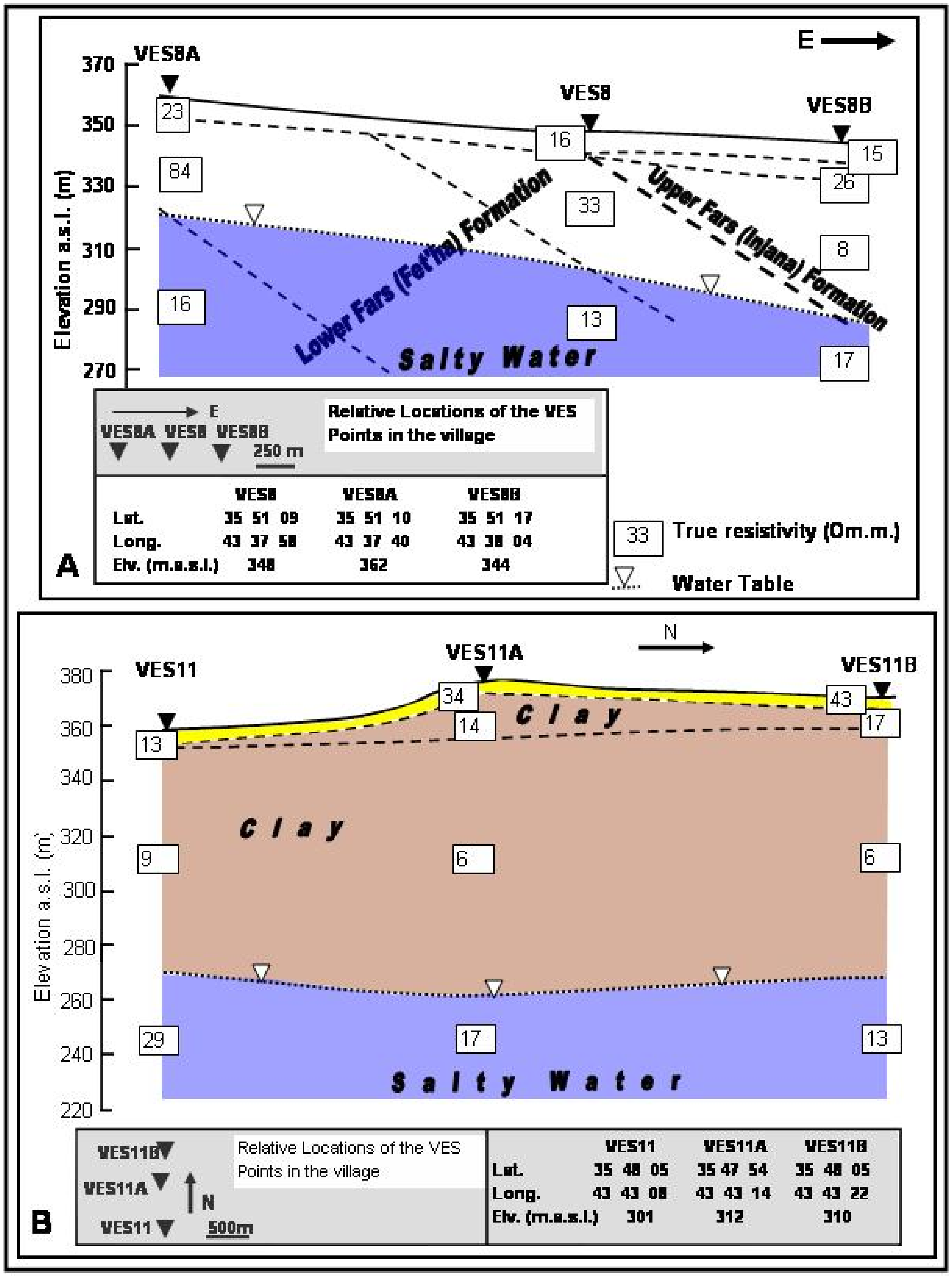

Fig. 10: Geo-electric Sections in Malik Agha (A), Chghlok (B)

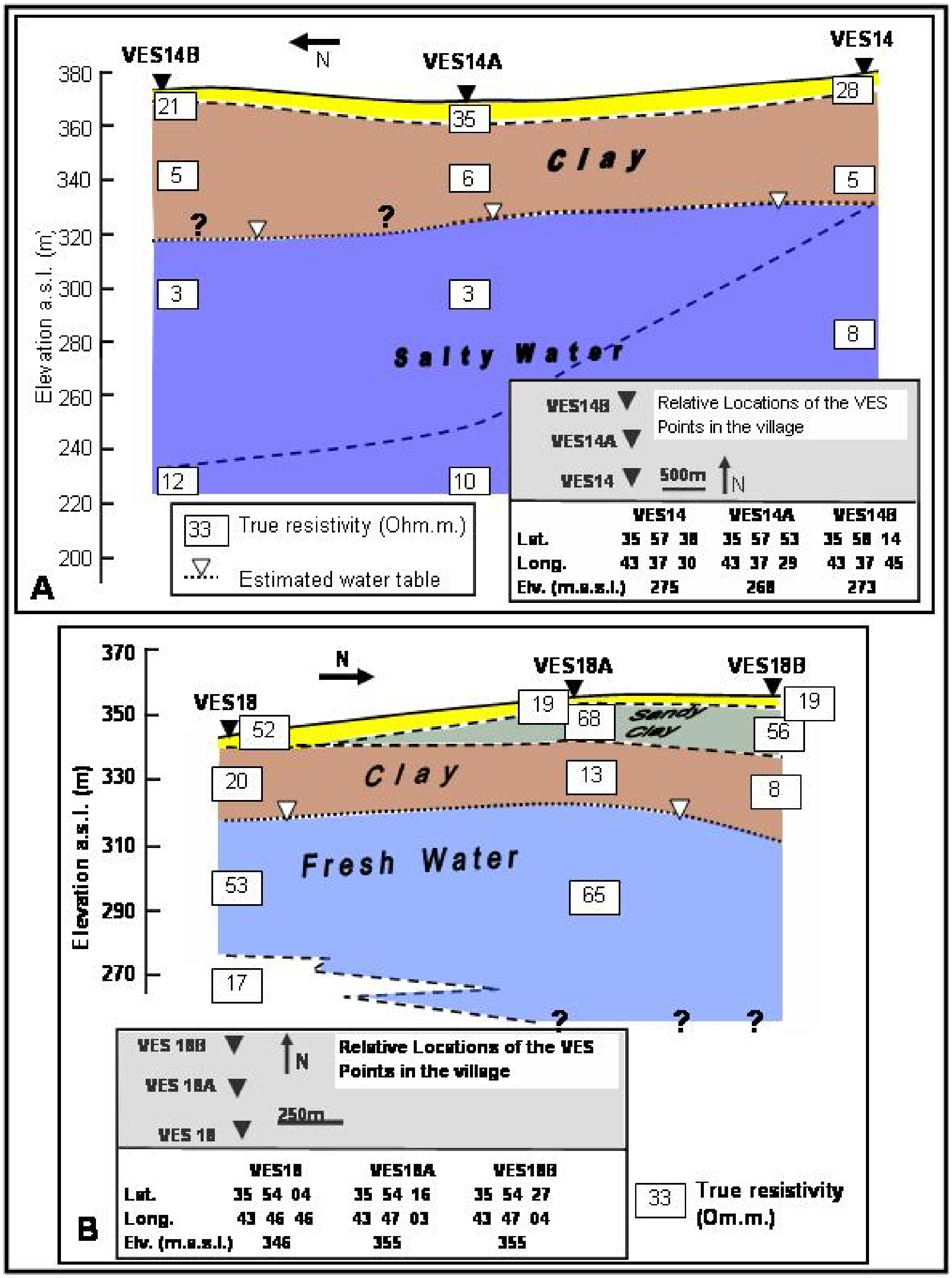

Fig. 11: Geo-electric Sections in Said Obied (A) and Chilhaweza (B)