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Resistivity Survey for Groundwater in Ezza North Using Vertical Electrical Sounding

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Abstract- Vertical electrical resistivity soundings were conducted in order to delineate the groundwater potentials at some locations in Ezza North Local Government of Ebonyi State. Twelve vertical electrical soundings were obtained using the Schlumberger configuration with the aid of the OHMEGA terramenter (SAS1000).The field data were subjected to interpretation by employing the method of manual partial curve matching techniques using the master curves and the corresponding auxiliary curves. A computer programme (RESOUND) was also used to interpret the data. The parameters obtained were used to determine the resistivities and thicknesses of the subsurface layers. The major lithologic units of the area are shales, sandstone and mudstone. The water bearing rocks were interpreted to exist at depths between 20m and 130m. The results fairly correlated with some logged boreholes close to the survey area. The aquifers have resistivities ranging between 9Ωm and 110Ωm. The geophysical search for groundwater has shown that the survey area has good groundwater potentials which if exploited would go a long way in reducing the problems of seasonal water shortage and health problems associated with the consumption of unhygienic surface water in the area.

Keywords: Resistivity, VES, groundwater, terrameter, geoelectric layer, aquifer

1.0 Introduction

Greater percentage of the earth's surface is composed of water. These include seas, oceans, rivers, streams and ponds among others. None of the surface water is as hygienic or as economical for exploitation as the groundwater (Singh, 2007). The amount of fresh water available for human use is less than 0.08% of all the water on the planet (BBC Sci/Tech News, 2003). Groundwater is recommended for its natural microbiological quality and its general chemical quality for most uses (McDonald *et al.,* 2002). Due to its scarcity, water related diseases are found in many parts of the world. In Nigeria, for example, Okoronkwo (2003) attributed the guinea worm infestation in some parts of Ebonyi State to ignorance and lack of safe drinking water. The people, according to him, lacked boreholes and depended only on ponds and other existing contaminated sources.

Over the years, boreholes have usually been drilled with or without previous knowledge of the subsurface stratification. This has led to so many failed boreholes (Selemo *et al.,* 1995). Due to the importance of groundwater, researches grew towards minimizing failed boreholes, thereby reducing the risk as well as cost of drilling (Adetola and Igbedi, 2000).

The electrical resistivity method is cost effective and has been found successful for locating groundwater. The apparent resistivity of the subsurface, measured from the surface, is a function of the current, the potential difference and the geometry of the electrode array. Presence of water considerably controls the variation of the resistivities in the shallow subsurface. Water-bearing rocks and minerals have lower resistivities. Resistivity measurements can thus indicate the level of water saturation and connectivity of pore spaces (McDougal *et al.,* 2003; Ezema, 2005). Several authors have successfully applied the resistivity method in groundwater exploration (Alile *et al.,* 2008; Adetola and Igbedi, 2000; Obiakor, 1984; Singh *et al.,* 2006; Mohammed and Lee, 1985; McDougal *et al.,* 2003 and Eduvie, 2000).

The present survey work is aimed at investigating the groundwater potentials of some selected communities within Ezza North Local Government Area of Ebonyi State by conducting vertical electrical soundings and interpreting the VES data obtained at the various locations.

1.1 Location and Geology of the Study Area

The area under survey lies between latitudes 6.13^0 and 6.28^0 north of the equator and longitudes of 7.87^0 and 8.00^0 east of the Greenwich Meridian. The map of the area under survey is shown in figure 1.1. The area which covers about 246km^2 lies in the south eastern part of Abakaliki, off Enugu-Ogoja highway. Abakaliki is about 62km South East of Enugu and about 22 kilometres West of Afikpo in Ebonyi State. The study area belongs to the Asu River group shales. According to Umeji (1985), the sediments of the Asu River group were formed during the Albian times. It was folded into open North-East trend known as the Abakaliki Anticlinorium and Afikpo Syncline. The Asu River group is overlain by succession of shales, siltstone and sandstone. There are some mineral intrusions which may have contributed to its numerous fractures. Lead – zinc mineralization and the associated mineralization like pyrites, chalcopyrite, salt and so on, occur in sills and dikes forming massive bodies (Orajaka, 1972).

The geological survey work done around the area reveals that the location is part of the Ebonyi formation. This formation overlies the Abakaliki siltstone and sandstone previously referred to in literature as "Unknown Formation" (Reyment, 1965). It is now, however referred to as the Ebonyi Formation (Agumanu, 1990). The Ebonyi River (wrongly spelt "Aboine"

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in published maps (Federal Survey, Nigeria, 1967) and its tribulataries, namely Akaduru, Nramura and Isumutu Rivers form the major drainage system in the area. Most of the numerous streams existing in the area are seasonal. The formation consists of a rapidly alternating horizontal sequence of mudstone, shale, limestone, siltstone and sandstone. The study area has elevation between 57*m* and 89*m* above the sea level.

Fig. 1.1.

2.0 Theory of Resistivity Surveying

In electrical resistivity surveying, direct current or low frequency alternating current signal is sent into the ground with the aid of two current electrodes (Dobrin, 1976) and the resulting potential difference recorded by a sensitive instrument at various locations on the surface of the earth. The information from the data can be used to deduce the resistivity and hence the geoelectric section of the ground. For a homogeneous isotropic medium, the Ohm's law of electrical conduction can be stated as

$$\underline{J} = \sigma \underline{E} \quad \text{or} \quad \underline{J} = \underline{E}/\rho,$$

where $\underline{J}$ is the current density, σ the conductivity of the earth, $\underline{E}$ the electric field and ρ is the resistivity. The resistivity obtained when two current electrodes A and B and two potential electrodes M and N are arranged as shown in fig. 2.1 is given by

$$\rho = \frac{2\pi}{\left(\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}\right)} \frac{\Delta V}{I}$$

where ΔV is the potential difference between M and N and I is the magnitude of current passed into the ground. In practice, for non homogenous stratified ground, this value is expressed as apparent resistivity ρ_a.

$$\rho_a = \frac{2\pi}{\left[\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}\right]} \left(\frac{\Delta V}{I}\right) = G\frac{\Delta V}{I}$$

where G is called the *geometrical factor* which depends only on the spatial arrangement of both the current and the potential electrodes. The physical quantities measured in field determination of resistivity are current I, flowing between two current electrodes, the potential difference ΔV between the two measuring potential electrodes, and the distance between the various electrodes (Keller and Frischknecht, 1966).

Fig.2.1

Vertical electrical sounding (VES) has been one of the most important geophysical methods for water prospecting in many areas (Parasnis, 1986). The essential idea behind VES is the fact that as the distance between the current electrodes is increased, the current passing across the potential electrodes carries a current fraction that has returned to the surface after reaching deeper levels.

There are many different types of electrode arrays that can be used in resistivity surveying (Brown and Respher**,** 1972; Robinson and Coruh**,** 1988; Keller and Frischknecht, 1966 and Lowrie, 1997). The most commonly employed geometrical configurations are the Wenner array and the Schlumberger array. Each of the electrode arrangements has its own advantages and disadvantages depending on the aims of the survey. In the Schlumberger array (which we used during this work), the current electrodes are spaced much further apart than the potential electrodes as shown in fig 2.2, such that *AM = BN = a –b/2 and BM =AN = a + b/2.*

Fig.2.2

This gives

$$\rho_a = \pi\left(\frac{a^2}{b} - \frac{b}{4}\right)\frac{\Delta V}{I} \quad \text{or} \quad \rho_a = GR$$

The potential electrodes are kept fixed while the current electrodes are expanded symmetrically about a central point. To maintain measurable potentials, it is however necessary to increase the potential electrode spacing (*MN = b)* at very large current electrode spacing. In addition to overcoming the large amount of work required to move the electrodes as in the Wenner array, the Schlumberger configuration has other advantages. The lateral resolution is better (Keller, and Frischknecht, 1966), because resistivity is sampled between the relatively small spacing M and N. Also the potential and current electrodes can be changed independently. Moreover, in Schlumberger arrangement, the speed of operation is increased, cable requirement is less and errors due to surface inhomogeneity between the potential electrodes are easily detected.

3.0 Data Acquisition and Analysis

The period for the investigation was chosen between May and July when the ground was considerably moist. This ensured good electrical contact between the earth and the electrodes. The major equipment used in the field is the OHMEGA SAS1000 *terrameter* which measures and displays the ground resistance. The apparent resistivity is computed accordingly. In order to obtain good results, accounts were taken of some practical limitations to geoelectrical surveys. One of the major problems encountered during the field work was limited space for electrodes layout. We tried as much as possible to avoid locating the centre of spread at positions where buildings farmland and other structures could limit the space for the field work. This notwithstanding, we were unable to reach up to our desired spread length of 1000*m* in some cases. As the presence of buried pipelines, cables and other metallic conductors could constitute electrical noise, none of the sounding points was located in the vicinity of such conductors. Although it may be necessary to carry out the electrical resistivity work when the ground is wet, the survey work was not carried out on the days when there were heavy down

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pour. Water logged soil may result into enormously high conduction near the ground surface. A total of twelve sounding profiles were collected from the selected communities.

Processing of the field data started in the field while the field work was still in progress. The apparent resistivity was later plotted against half the electrode spacing, *AB/2* on log-log graph sheet with the same modulus as the theoretical curves. These were used during the interpretation by manual partial curve matching with the aid of master and auxiliary diagrams (Eric and Joachim, 1979). The sounding data were also subjected to computer interpretations using the software RESOUND. Figure 4.1 shows the computer model curves.

4.0 Results and Discussions

The obtained results were interpreted using both the manual curve matching procedures and computer based interactive modelling. The model curves resulting from the computer – based interpretation of the sounding data are shown in figure 4.1 while the corresponding results are shown in table 4.1. Table 4.2 shows the estimated depths to the aquifers.
The results of the twelve vertical electrical soundings of the selected locations indicated between five to eight geoelectric layers. The thicknesses of the top layers vary between 0.8*m* to 1.0*m*. These are the top lateritic sand overburden soil observed during the field work.

Table 4.1
Fig.4.1
Table 4.2
Fig. 4.2
Table 4.3

The intermediate layers are suggested to comprise of sandstones and mainly shales as reported by the literature on geology of the area (Agumanu, 1990; Umeji, 1985). Most of the field curves show trend of initial decrease and later increase in resistivities with depth to the sounding probes. The initial decrease in resistivities could be as a result of increase in water saturation. The lower values encountered before the rise in resistivities could be attributed to the water saturated fractured shale and mudstone aquifers which are the major water bearing rocks in the survey area.

The vertical electrical sounding positions for VES 1, 3, 4, 5, 6, 9 and 10 were obtained at approximately along the North-South direction of the Western region of the study area. The geologic section relating the inferred formations of VES 1, VES 3, VES 4, VES 5, VES 6, VES 9 and VES 10 is depicted in figure 5. The borehole drilled by the Geological Survey of Nigeria (GSN BH) near VES 1, is also shown beside this cross section.

4.1 Conclusion

Based on the above interpretations, five profiles indicated five geoelectric layers. Another five profiles indicated six layers while the remaining two show eight layers each. The water bearing formations were probably due to fractured shales which occurred at varying depths between 20*m* to 70*m* at most VES stations. These fairly correlated with logged boreholes at the nearby communities with aquifers between 40*m* and 70*m* deep, though the depths of few cases were interpreted to about between 80*m* and 130*m*.

The results of our geophysical survey for groundwater have shown that the selected locations in Ezza North Local Government Area of Ebonyi State have good groundwater potentials. Hence the exploitation of groundwater at the proposed locations will help reduce the existing seasonal water scarcity, long distance trekking in search of water and overcrowding of the few and possibly contaminated streams, rivers and ponds. It will also go a long way in improving the peoples health conditions (Malin, 1982) by minimizing the cholera, guinea-worm and other water related diseases around the study area.

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Table 4.1: *Resistivity data for the various VES points*

S/N	$\frac{AB}{2}(m)$	$\frac{MN}{2}(m)$	Geometrical factor (G)	Apparent Resistivity $\rho_a\ (\Omega m)$												
				VES 1	VES 2	VES 3	VES 4	VES 5	VES 6	VES 7	VES 8	VES 9	VES 10	VES 11	VES 12	
1	1.5	0.50	6.28	1164	647	636	84	580	1017	171	957	382	931	640	1300	
2	2.0		11.78	523	575	524	85	483	966	173	1147	317	901	610	1391	
3	2.5		18.85	425	495	434	76	427	883	163	1247	235	801	624	1440	
4	3.5		37.70	290	381	293	59	311	944	153	1048	171	629	525	1240	
5	4.5		62.80	209	310	179	51	225	649	135	1560	146	500	777	1052	
6	6.0		112.32	138	246	113	44	147	466	115	1281	126	338	534	821	
7	8.0		200.00	103	198	65	45	92	264	91	908	116	237	299	604	
8	10.0		313.00	75	160	38	39	74	160	79	554	99	149	297	319	
9	15.0		706.00	58	881	53	41	66	77	77	127	83	92	188	275	
10	10.0	3.50	39.39	110	148	59	48	76	179	52	51	93	162	104	497	
11	15.0		95.49	70	147	44	52	61	70	183	85	74	88	82	310	
12	20.0		174.04	64	62	42	55	58	57	437	117	63	71	75	225	
13	25.0		275.03	61	88	41	59	55	56	914	520	58	67	76	177	
14	35.0		544.35	60	71	45	71	54	54	834	215	52	66	89	151	
15	45.0		903.44	64	116	1613	78	54	54	1288	808	52	63	76	139	
16	55.0		1352.29	64	43	722	84	56	58	86	375	53	64	78	150	
17	45.0	14.0	205.24	45	46	43	11	47	61	77	55	51	70	79	172	
18	55.0		317.45	17	42	44	28	51	66	77	51	52	70	88	141	
19	75.0		609.21	78	43	32	403	56	73	78	49	63	66	102	206	
20	95.0		990.74	132	38	145	212	61	77	75	57	64	62	121	103	
21	125.0		1731.35	123	25	46	35	64	81	73	46	57	59	153	192	
22	165.0		3033.04	142	3	9	41	58	86	70	48	49	60	173	141	
23	215.0		5165.11	65	1049	198	326	50	82	44	39	51	52	139	134	
24	165.0	55.0	691.24	117	31	467	87	55	80	78	60	270	57	133	126	
25	215.0		1233.95	61	28	2260	78	28	84	63	58	1711	51	137	120	
26	280.0		2152.98	43	28	3930	82		95	59	44	759	50	141	196	
27	370.0		3823.96	26	21	1503	60		87	53	36	372	57	90	264	
28	500				60	4550										

Table 4. 2: *The results of the computer interpretations of the geoelectric VES data from various profiles*

Geoelectric layer	Resistivity (Ωm)	Thickness (m)	Cumulative thickness (m)
1	985.0	0.8	0.8
2	220.0	2.7	3.5
3	36.0	30.5	34.0
4	350.0	21.0	55.0
5	480.0	50.0	105.0
6	15.0	-	-
VES 1 (Adiagu Oguji			

Geoelectric layer	Resistivity (Ωm)	Thickness (m)	Cumulative thickness (m)
1	430.0	1.0	1.0
2	288.0	1.0	2.0
3	88.0	14.0	16.0
4	14.5.0	44.0	60.0
5	4.0	48.0	108.0
6	9.0	-	-
VES 2 (Ekka Town Hall)			

Geoelectric layer	Resistivity (Ωm)	Thickness (m)	Cumulative thickness (m)
1	385.0	0.8	0.8
2	250.0	1.2	2.0
3	18.0	18.0	20.0
4	10.0	12.0	32.0
5	458.0	-	-
VES 3 (Nkomoro – Omuzor)			

1	55.0	0.8	0.8
2	30.0	1.2	2.0
3	19.0	22.0	24.0
4	325.0	41.0	65.0
5	285.0	-	-
VES 4 (Ndiegu-Ogboji)			

1	702.0	0.8	0.8
2	360.0	1.7	2.5
3	49.0	12.5	15.0
4	51.0	31.0	46.0
5	122.0	64.0	110.0
6	8	-	-
VES 5 (Umundiegu Ohaike)			

1	1008.0	0.8	0.8
2	1385.0	1.7	2.5
3	54.0	17.5	20.0
4	65.0	40.0	60.0
5	92.0	49.0	109.0
6	98.0	-	-
VES 6 (Udenyi Azuakparata)			

1	110.0	1.0	1.0
2	110.0	1.0	2.0
3	50.0	6.0	8.0
4	250.0	42.0	50.0
5	70.0	-	-
VES 7 (Inyere-Ngangbo)			

1	90.0	1.0	1.0
2	400.0	1.5	2.5
3	60.0	12.5	15.0
4	750.0	45.0	60.0
5	50.0	-	-
VES 8 (Ogbuji-Eguo-Ugwu)			

1	900.0	1.0	1.0
2	240.0	3.0	4.0
3	120.0	21.0	25.0
4	50.0	15.0	40.0
5	180.0	40.0	80.0
6	90.0	-	-
VES 9 (Ohaccara-Ndiegu)			

1	1100.0	2.0	2.0
2	170.0	6.0	8.0
3	50.0	17.0	25.0
4	65.0	70.0	95.0
5	40.0	-	-
VES 10 (Ndiegu Ekka)			

1	360.0	0.9	0.9
2	185.0	0.6	1.5
3	950.0	1.5	3.0
4	42.0	2.0	5.0
5	65.0	15.0	20.0
6	120.0	55.0	75.0
7	652.0	57.0	132.0
8	150.0	-	-
VES 11 (Ekka Integrated School Ekka)			

1	1452.0	0.9	0.9
2	3854.0	0.6	1.5
3	1350.0	1.5	3.0
4	225.0	7.0	10.0
5	150.0	10.0	20.0
6	115.0	55.0	75.0
7	110.0	55.0	130.0
8	458.0	-	-
VES 12 (Ohaugo Primary School)			

Table 4.3: *Estimated depths of the water bearing rocks at the VES points.*

VES	LOCATION	Geoelectric layer	ρ (Ωm)	THICKNESS (m)	DEPTH FROM SURFACE (m)	REMARKS
1	Adiagu Oguji	3 6	36 15	31 infinity	34 >105	Perched aquifer: about 34***m*** deep. Main aquifer: from depth of about 105*m*.
2	Ekka Town Hall	5 6	4 9	48 infinity	108 >108	Main aquifer : from the depth of about 108*m*
3	Nkomoro – Omuzor	4	10	12	32	A shallow thin aquifer: 32*m* deep. (Borehole is not strongly recommended here)
4	Ndiegu-Ogboji Ukwu Akpara	3	19	22	24	A shallow aquifer. (Borehole is not strongly recommended here)
5	Umundiegu Ohaike	3/4 6	49/51 8	44 infinity	46 >110	Perched aquifer: 46m. Main aquifer: from depth of about 110*m*.
6	Udenyi Azuakparata	3/4	54/65	58	60	Depth to aquifer: about 60*m*
7	Inyere-Ngangbo	5	70	infinity	>50	Main aquifer: from depth of about 50*m*.
8	Ogbuji-Eguo-Ugwu	5	50	infinity	>60	Main aquifer: from depth of about 60*m*.
9	Ohaccara-Ndiegu	4 6	50 90	15 infinity	40 >80	Parched aquifer: about 40*m* deep. Main aquifer: from depth of 80m.
10	Ndiegu Ekka	5	40	infinity	>95	Main aquifer: from depth of about 95*m*.
11	Ekka Integrated School	4/5	42/65	17	20	Shallow aquifer. (Borehole is not strongly recommended here)
12	Ohaugo Primary School	7	110	55	>130	Relatively deep aquifer.

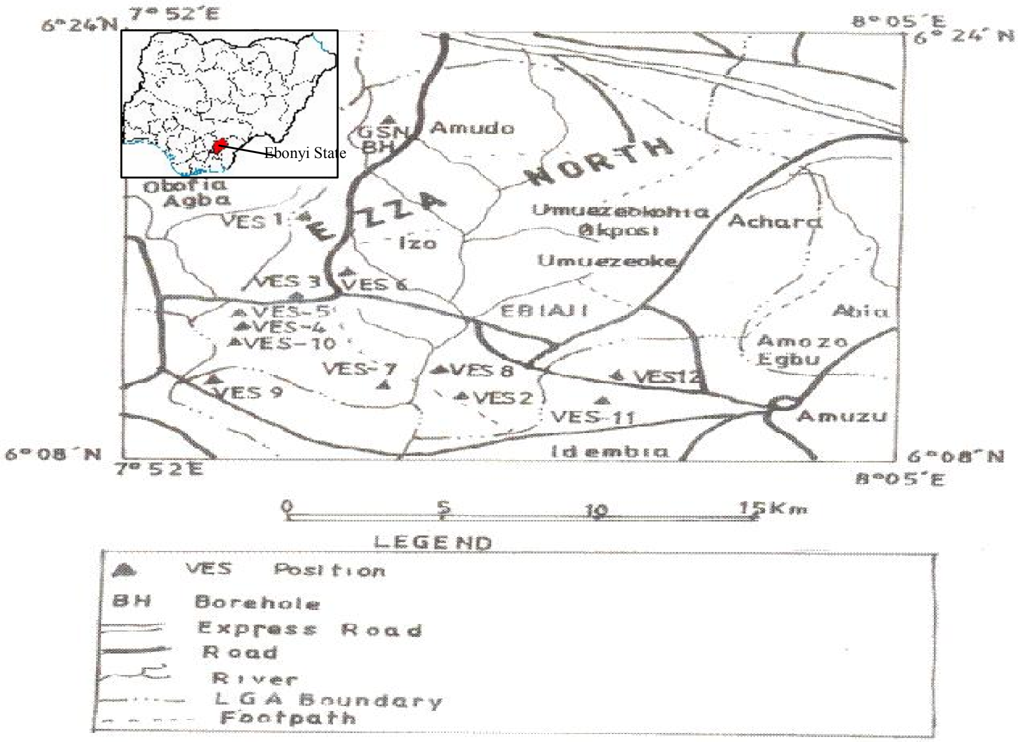

Fig. 1.1. *Map showing the location of the study area and the VES positions (Federal Survey, Nigeria, 1976). Map of Nigeria Showing the location of Ebonyi State is inserted* (http://commons.wikimedia.org/wiki/File:Ebonyi_State_Nigeria.png)

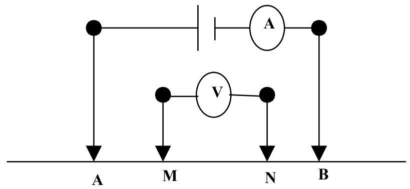

Fig 2.1: *Current electrodes (A and B) and potential electrodes (M and N) for measuring the earths resistivity* (Lowrie, 1997).

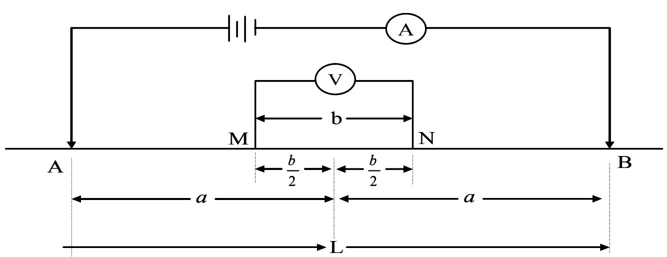

Fig. 2.2: *The Schlumberger array*

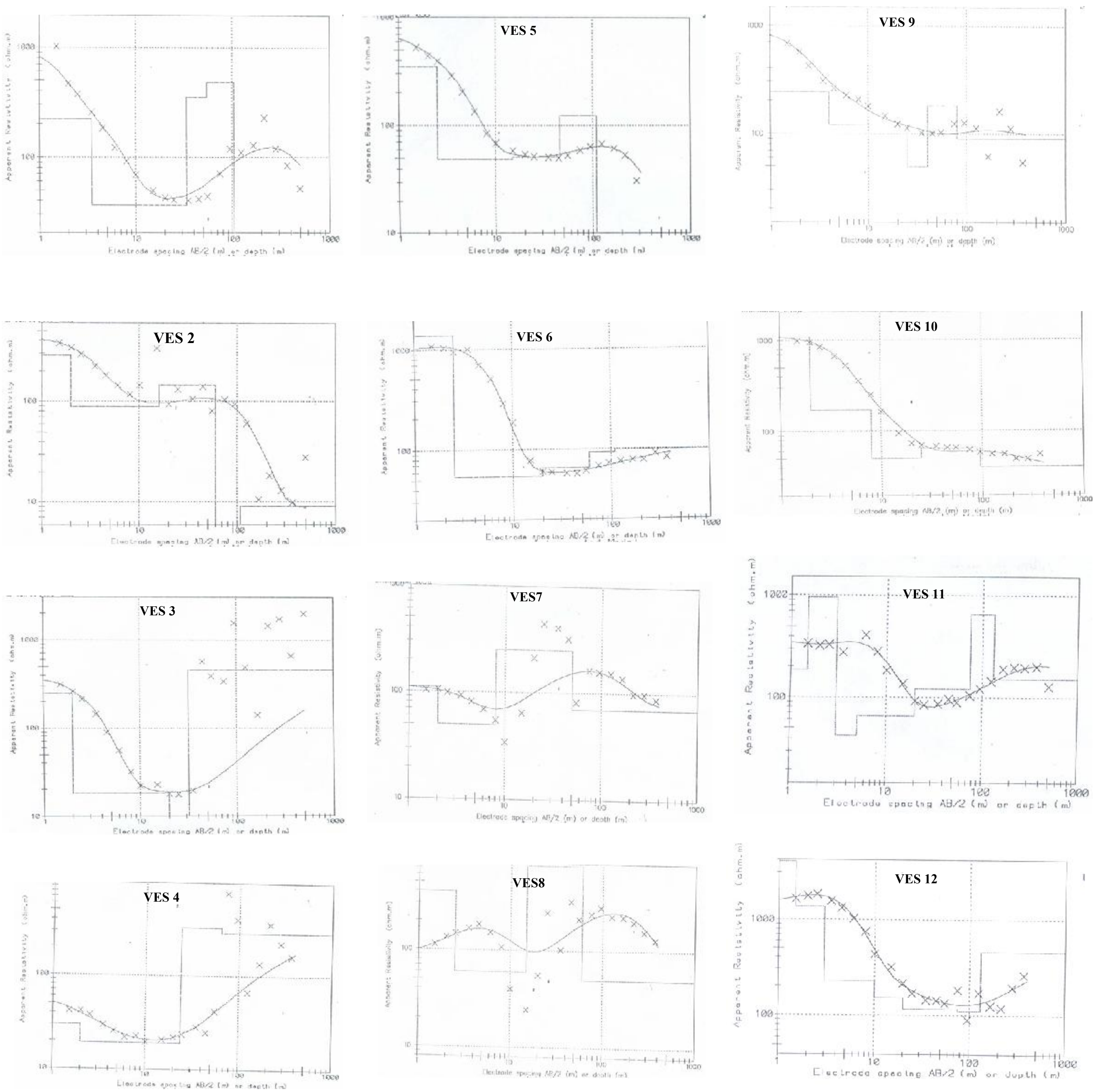

Fig. 4.1: *The models curves resulting from the computer based interpretation of the various sounding data. Crosses are the field points.*

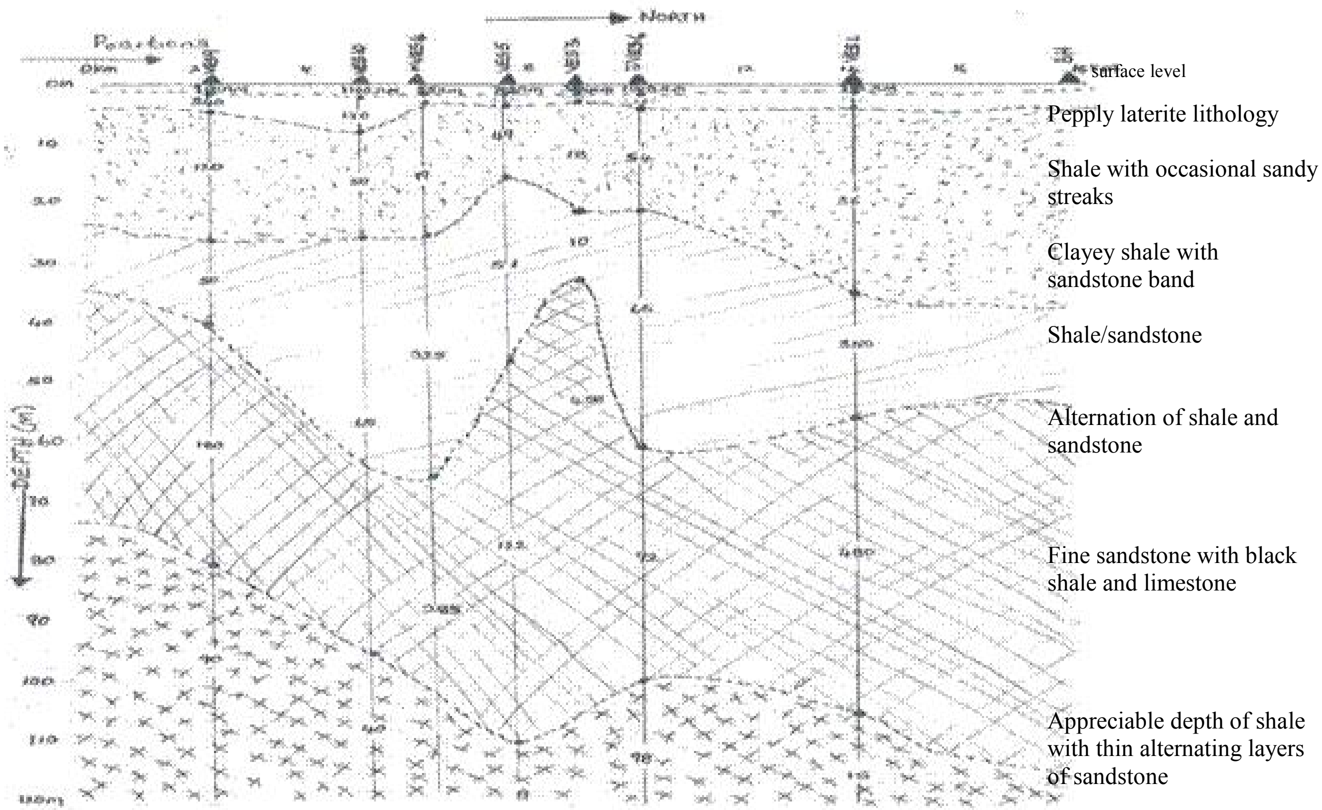

Figure 4.2: Geoelectric *section relating VES 9, 10, 4, 5, 3, 6 and 1, obtained approximately along the North-South direction of the western region of the study area. Depths are shown in m and resistivities in* Ω*m.*