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Application of 1-D and 2-D Electrical Resistivity Methods to Determine the Depth of Aquifer around Camp House in Canaan land, Ota Nigeria.

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Abstract

This research work was carried out to determine the depth of aquifer around Camp House in Canaan land, Ota, Nigeria. The depth to which the aquifer can be found was done by employing the Vertical Electrical Sounding (VES) method by engaging the Schlumberger electronic Array and the Wenner Array for the 2 – Dimensional imaging. Five (5) different VES reading and One (1) 2D traverse were carried out to provide very good subsurface information. The study was carried out using PASI Earth Resistivity Meter. WINRESIST software was used for the interpretation of the VES data and the 2D data was inverted using DIPPRO Window software program. The result from the curves indicates groundwater potential in the study area.

Keywords: electrical method, hydrogeological, resistivity, aquifer, Canaan land.

1.0 Introduction

Groundwater is the water that lies beneath the ground surface, filling the pore spaces between grains in bodies of sediments and filling cracks and crevices in all types of rock [1]. Underground water is characterized by a certain number of parameters which are determined by geophysical methods such as electrical resistivity methods, seismic methods, magnetic methods, gravity methods etc. But for this research work, the application of electrical resistivity survey method was used. The most usual parameters are the porosity, the permeability, the transmissivity and the conductivity. Electrical resistivity method in geophysical exploration for groundwater in a sedimentary environment has proven to be reliable [2]. Records show that the depths of aquifers differ from place to place because of variational geo-thermal and geo-structural occurrence [3, 4]. Electrical resistivity method is one of the most useful techniques in underground water geophysical exploration because the resistivity of rock is very sensitive to its water content. In turn, the resistivity of water is very sensitive to its ionic content. The geology of the study area reveals that the entire area is underlain by sedimentary rocks. These rocks are of ages between Paleocene to recent. The sedimentary rock contains about 90% of sandstone and shale intercalation. It is coarse grained/locally fine grained in some areas, poorly sorted, sub- angular to well-rounded and bears lignite streaks and wood fragment [5]. The sedimentary rock of the study area constitutes the Benin formation. This has an important groundwater reservoir. In order to locate a water supply tube-well that can serve a population of thousands of people, whether it be church members, workers, residents and even Covenant University students, a major geophysical mapping of the camp was carried out. This involved both 1D and 2D surveys. 1D electrical method using Vertical Electrical Sounding has been employed over the years to characterize aquifer in different geologic environments and to map fractures in basement area [7, 8, 9].

2.0 Resistivity Theory

Resistivity is expressed in ohm-meters, and is an estimate of the earth resistivity calculated using the relationship between resistivity, an electric field, and current density (ohm's law), and the geometry constant, spacing of the current and potential electrodes. Where the earth is not homogeneous and isotropic, this estimate is called the apparent resistivity, which is an average of the true resistivity in the measured section of the earth.

The fundamental theory behind the resistivity method is well expounded [9] and the theory has been adequately covered [10,11,12]. The Maxwell's equation for earth materials having dielectric and magnetic properties is given below [13].

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$$\nabla XH = J + \frac{\partial D}{\partial t} \quad (1)$$

$$\nabla \times \mathrm{E} = -\frac{\partial B}{\partial t} \quad (2)$$

$$\nabla . B = 0 \quad (3)$$

$$\nabla . \mathrm{D} = \mathrm{Q} \quad (4)$$

Where H = magnetic field strength.

$$\therefore \ \mathrm{H} = \frac{B - \mu M}{\mu}$$

The equation of continuity is obtained by taking the divergence of equation 1

i.e $\nabla . \nabla \times H = \nabla . J + \nabla . \frac{\partial D}{\partial t}$

But the divergence of a curl is zero, hence

$$\nabla . J - \nabla \frac{\partial D}{\partial t} = 0$$

Therefore, $\nabla . J = -\frac{\partial}{\partial t} \nabla D$ (5)

This is so because the order of derivatives with respect to co-ordinate and time can be reversed. Substituting equation 4 into equation 5 we have

$$\nabla . J = -\frac{\partial}{\partial t} Q \quad (6)$$

The resistivity method operates in the absence of a field of induction and is based on observations of an electric field maintained by direct current.

However, for source free regions of the earth, equation (2) and (6) become:

$$\nabla \times E = 0 \quad (7)$$

$$\nabla . J = 0 \quad (8)$$

Equation (7) suggests that the electric field strength may be expressed as the gradient of a scalar potential (v):

$$E = -\nabla V \quad (9)$$

However, Ohm's law provides the relationship between E and J and it states that the current density is proportional to the electric field strength:

$$J = \sigma E \quad (10)$$

This proportionality constant is called conductivity.

It must be noted that for an isotropic medium, the conductivity will be a scalar quantity so that $\underline{J}$ and $\underline{E}$ will be in the same direction. In general, $\underline{J}$ and $\underline{E}$ are not in the same direction because conduction might be easier in one direction rather than another. Such a medium is said to be anisotropic and the conductivity is a tensor of second rank, the subscripts i, j and k may be any of the x, y or z spatial directions in a rectangular co-ordinate system. Ohm's law becomes:

$\underline{J} = \sigma_{rj} \underline{E}$ or, more fully:

$$\begin{vmatrix} J_x \\ J_y \\ J_z \end{vmatrix} = \begin{vmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{xxz} \\ \sigma_{yx} & \sigma_{yy} & \sigma_{yz} \\ \sigma_{zx} & \sigma_{zy} & \sigma_{zz} \end{vmatrix} \begin{vmatrix} E_x \\ E_y \\ E_z \end{vmatrix} \quad (11)$$

Combining equations (8), (9) and (10) gives a differential equation which is basis of all resistivity prospecting with direct current:

$$\nabla(\sigma_{\mathrm{rj}} \nabla V) = 0 \quad (12)$$

In this isotropic case where the conductivity at a point in the ground is independent of direction, equation (11) reduces to Laplace's equation:

$$\nabla_2 \nabla \mathrm{V} = 0 \quad (13)$$

Solution to equation (11) and (12) may be developed for a particular model of the earth by selecting a co-ordinate system to match the geometry of the model and by imposing appropriate boundary conditions.

Where B = Magnetic flux density, t = time, μ_0 = Permeability of free space, P = Polarization, M = Magnetization, Q = electric charge density, J = Current density, E = Electric field strength, D = Electric displacement = ε_0 $\underline{E}$ + $\underline{P}$, and ε_0 = Permittivity of free space

3.0 Methodology

In this research work, the 1-D and 2-D Resistivity methods were used because it responds favourably to measurable parameters that can easily distinguish the aquifer from other formations. The conductivity (resistivity reciprocal) variations of formations will enable one delineate different layers using the PASI Terrameter. Electrical resistivity varies with rock or sediment type, porosity and the quality and quantity of water and is a fundamental property of earth materials. Electricity can be conducted in the earth electrolytically by interstitial fluids (usually water) and electronically by certain materials, such as clay minerals, by cation exchange. As a result, poorer quality ground water (that is water with higher concentrations of dissolved solids) or sediments with higher clay content are usually more conductive [14].

4.0 Results, Analysis and Discussion

4.1 1-D Resistivity Result and Interpretation

The first step in the interpretation of the resistivity sounding survey was classification of the observed apparent resistivity curves into types. This classification is primarily made on the basis of the shapes of the curves, but at the same time it is related to the geological situation in the subsurface. The shape of a VES curve depend on the number of layers in the subsurface and the thickness of each layer. Model parameters estimated from the data were used for computer iterative operations to interpret the data. In the iterative interpretation method used in this study, the field data were compared with the data derived from a layer model obtained by curve matching. If the agreement between the two sets of data is unsatisfactory, then the parameters of the layer model are adjusted.

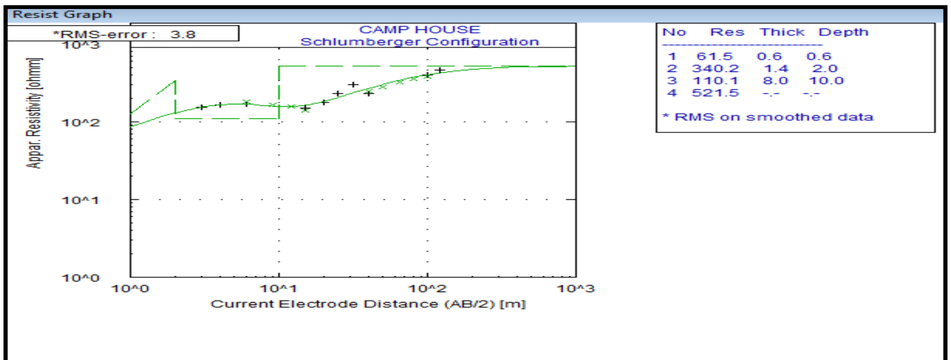

Fig. 4.1: VES Curves, Resistivity of layers, Thickness and Depth Table for Location 1

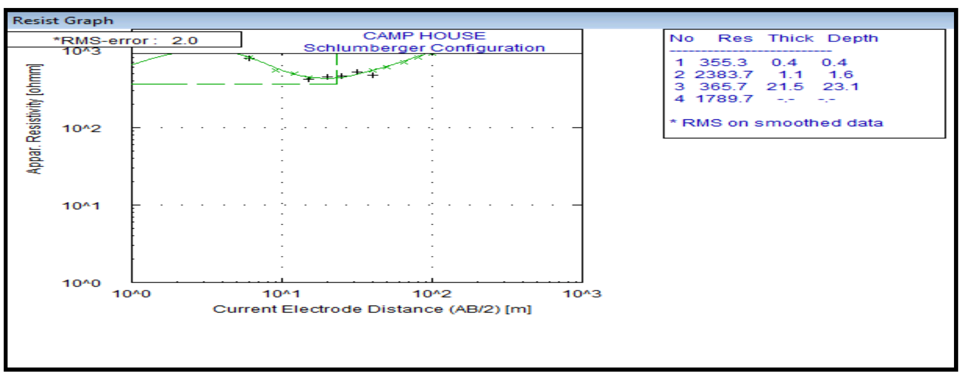

Fig. 4.2: VES Curves, Resistivity of layers, Thickness and Depth Table for Location 2

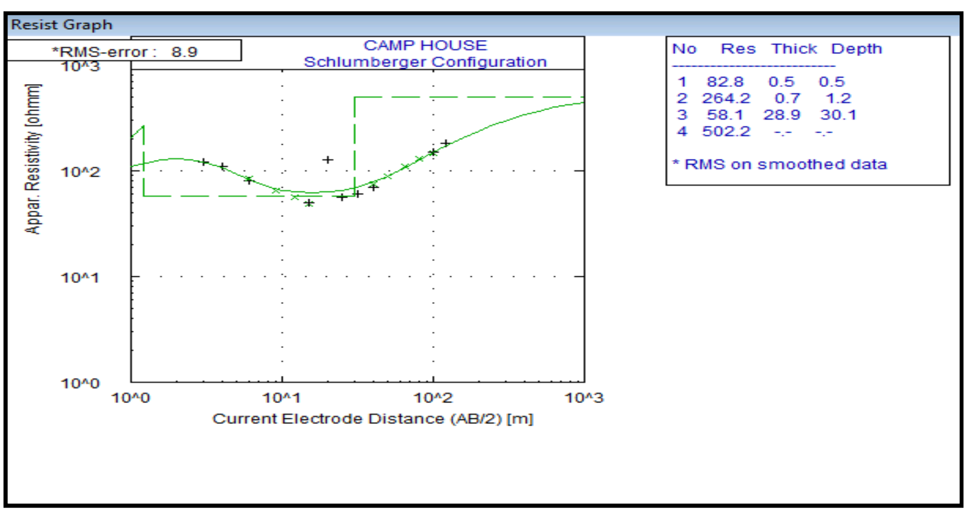

Fig. 4.3: VES Curves, Resistivity of layers and Thickness, Depth Table for Location 3

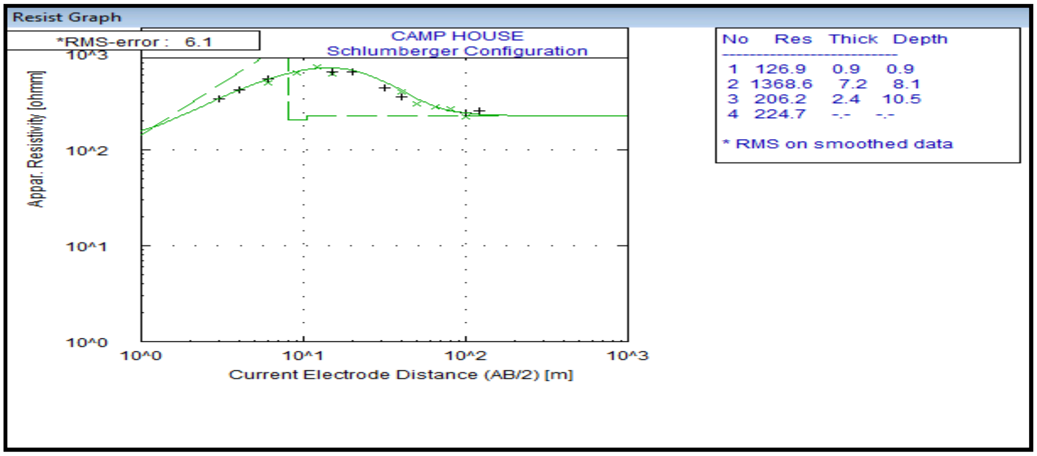

Fig. 4.4: VES Curves, Resistivity of layers and Thickness, Depth Table for Location 4

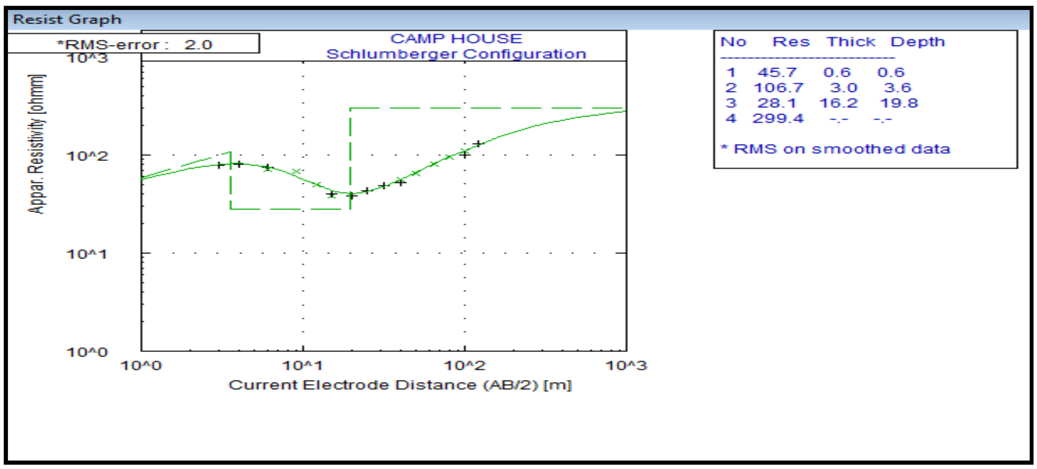

Fig. 4.5: VES Curves, Resistivity of layers, Thickness and Depth Table for Location 5

This procedure was repeated until a sufficient agreement between the model data and the field data was obtained. Therefore the model parameters, observed data and computed data as well as the theoretical curves for the area covered in this study are used in delineating the geoelectric sections and the geologic sections respectively. In the figures below, the apparent resistivity values (ohms) were plotted against current electrode spacing (AB/2) (m) by the software. An iteration process was then commenced until a good fit was obtained.

From VES 1, VES 2, VES 3 and VES 5, we can assume that a permeable formation with water holding capability (e.g. clay, sand) is present in layer 3 as a result of the low resistivity(with a range of 28 Ωm -115Ωm) at a depth which ranges between 10m-30m(33.3ft – 99.9ft). This depth would most likely be the depth of the aquifer.

4.2 2-D Resistivity Result and Interpretation

One (1) 2D traverse was carried out to provide better information and possibly give clue to groundwater condition/situation of the area. The 2D data was inverted using DIPPRO for Window software program. The distribution of resistivity along inverted model resistivity pseudosection perfectly agrees with 3 – 4 geoelectric layers identified from VES results.

The resistivity table for the transverse is seen below:

Table 1: Traverse 1 (a=10m): (Current and Potential electrode spread, resistance and resistivity)

Transverse 1 a= 10m					
C1	P1	P2	C2	R	?(Ωm)
0	10	20	30	7.9	496.436
10	20	30	40	1.5	94.26
20	30	40	50	2.6	163.384
30	40	50	60	5.7	358.188
40	50	60	70	11.7	735.228
50	60	70	80	8.7	546.708
60	70	80	90	5.7	358.188
70	80	90	100	15.8	992.872
80	90	100	110	12.6	791.784
90	100	110	120	7.2	452.448
100	110	120	130	67.7	4254.268
110	120	130	140	65.7	4128.588
120	130	140	150	30.4	1910.336
130	140	150	160	17.4	1093.416
140	150	160	170	7.7	483.868
150	160	170	180	37.7	2369.068
160	170	180	190	6.8	427.312
170	180	190	200	63.6	3996.624
180	190	200	210	5.4	339.336
190	200	210	220	54.4	3418.496

Table 2: Traverse 1 (a=20m, a=30m): (Current and Potential electrode spread, resistance and resistivity)

C1	P1	P2	C2	R	?(Ωm)
0	20	40	60	31.2	3921.216
10	30	50	70	17.7	2224.536
20	40	60	80	7.8	980.304
30	50	70	90	4.7	590.696
40	60	80	100	14.8	1860.064
50	70	90	110	13.8	1734.384
60	80	100	120	6.1	766.648
70	90	110	130	66.5	8357.72
80	100	120	140	64.9	8156.632
90	110	130	150	29.5	3707.56
100	120	140	160	16.5	2073.72
110	130	150	170	6.6	829.488
120	140	160	180	49.7	6246.296
130	150	170	190	5.8	728.944
140	160	180	200	5.7	716.376
150	170	190	210	22.3	2802.664
160	180	200	220	58.9	7402.552
Transverse 1 a=30m					
C1	P1	P2	C2	R	?(Ωm)
0	30	60	90	5.4	1018.008
10	40	70	100	6.6	1244.232
20	50	80	110	7.5	1413.9
30	60	90	120	16.5	3110.58
40	70	100	130	28.6	5391.672
50	80	110	140	11.6	2186.832
60	90	120	150	20.6	3883.512
70	100	130	160	6.3	1187.676
80	110	140	170	5.6	1055.712
90	120	150	180	8.8	1658.976
100	130	160	190	4.1	772.932
110	140	170	200	7.4	1395.048
120	150	180	210	34.1	6428.532
130	160	190	220	44.1	8313.732

Table 3: Traverse 1 (a=40m, a=50m, a=60m): (Current and Potential electrode spread, resistance and resistivity)

Transverse 1 a=40m					
C1	P1	P2	C2	R	ρ(Ωm)
0	40	80	120	2.4	603.264
10	50	90	130	38.8	9752.768
20	60	100	140	7.3	1834.928
30	70	110	150	54.4	13673.98
40	80	120	160	9.7	2438.192
50	90	130	170	5.4	1357.344
60	100	140	180	23.7	5957.232
70	110	150	190	23.6	5932.096
80	120	160	200	24.4	6133.184
90	130	170	210	49.4	12417.18
100	140	180	220		
Transverse 1 a=50m					
C1	P1	P2	C2	R	ρ(Ωm)
0	50	100	150	23.8	7477.96
10	60	110	160	27.6	8671.92
20	70	120	170	25.7	8074.94
30	80	130	180	68.9	21648.38
40	90	140	190	46.7	14673.14
50	100	150	200	57.9	18192.18
60	110	160	210	44.5	13981.9
70	120	170	220	11.4	3581.88
Transverse 1 a=60m					
C1	P1	P2	C2	R	ρ(Ωm)
0	60	120	180	13.4	5052.336
10	70	130	190	6.5	2450.76
20	80	140	200	13.1	4939.224
30	90	150	210	12.2	4599.888
40	100	160	220	10.2	3845.808

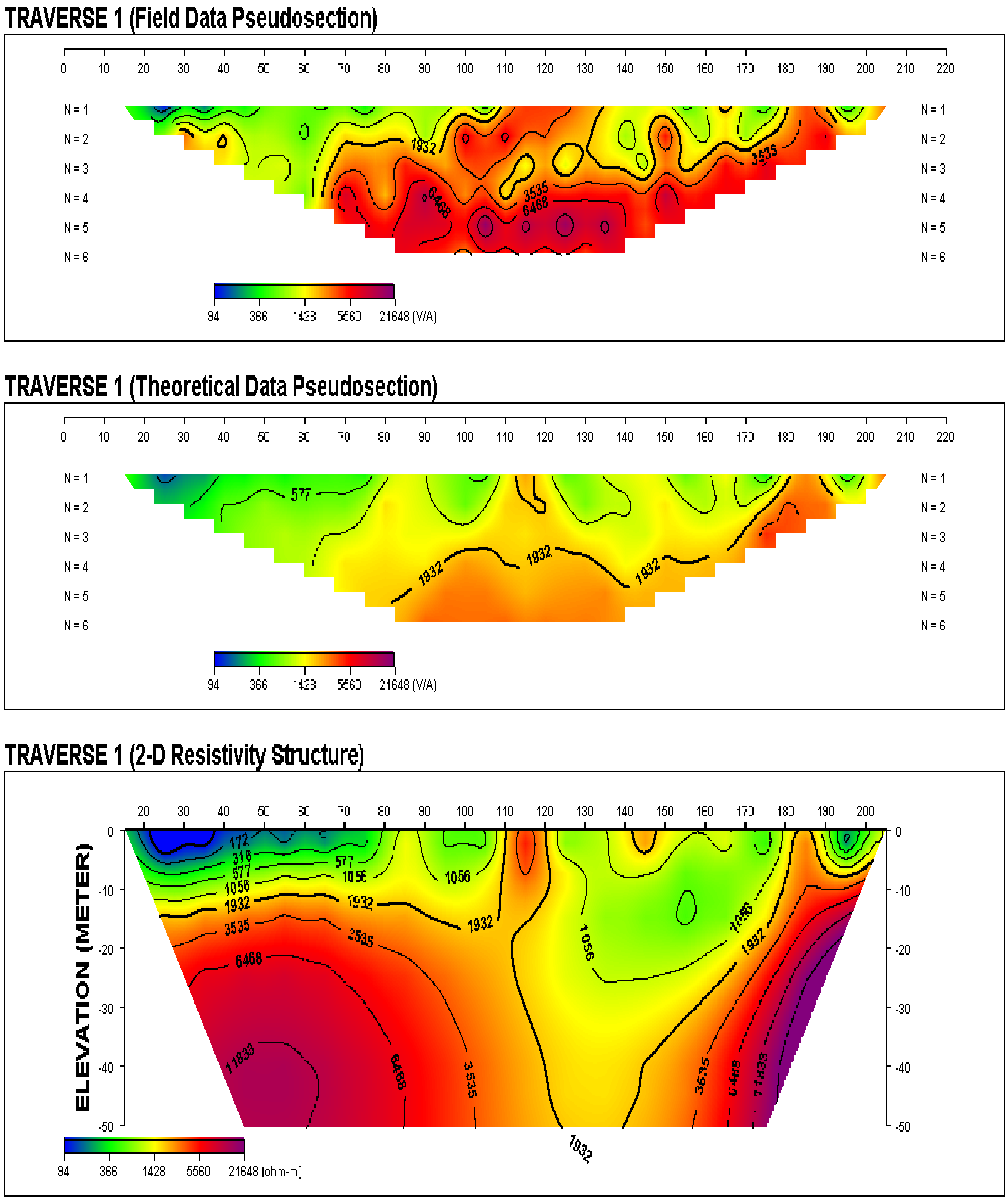

Figure 4.6: 2 – D resistivity traverse

5.0 Conclusion

This research provides information on the depth to the groundwater and also the thickness of the aquifer unit in the study area. This information is very relevant to the development of an effective water scheme for the area and possibly beyond to other areas underlain by the formation. It was also discovered that 2D survey gives a better result than 1D because of its ability to image the subsurface vertically and laterally which enhances continuity.

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