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Full Length Research Paper

Application of vertical electrical sounding method to decipher the existing subsurface stratification and groundwater occurrence status in a location in Edo North of Nigeria

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The interpretation of two resistivity curves over Iyakpi town within geologic terrain often referred to as Ajali formation which bears false-bedded sandstone with associated clay and shale intervals in the bottom section indicates that the area has an abundant groundwater potential. Existence of productive borehole in the study area was field-confirmed. The study area is said to have a standing history of abortive boreholes, resulting from failed drilling attempts. No dug well was sited in the community. The study showed that the main lithologic units penetrated by the sounding curves are laterite, sandstone, sandstone (dry with some clay/shale). This study revealed the possibility of having a maximum drill depth to water table of 260 m (865.80 ft).

Key words: Electrical, subsurface, stratification, groundwater occurrence.

INTRODUCTION

This paper describes the vertical electrical sounding investigation undertaken at Iyakpi, a type area of Ajali formation. The aim is to decipher the existing subsurface stratification and groundwater occurrence status of the site. Generally, a number of geophysical exploration techniques are available which enables an insight to be obtained rapidly in the nature of water bearing layers. These include geoelectric, electromagnetic, seismic and geophysical borehole logging. The choice of a particular method is governed by the nature of the terrain and cost considerations (Emenike, 2001).

Iyakpi lies around 3 km southeast of Auchi town in Edo state. The site is located around the geographical coordinates of latitude 07° 03′N and longitude 06° 17′E. The study area and its environs lie on a flat topographical terrain. Actual site observation and information from existing geological maps classify surface sand of the study area and its environs as members of the Ajali formation. The Ajali formation bears false-bedded sandstone with associated clay and shale intervals in the bottom section (Reyment, 1964). The Ajali Formation is successively underlain by materials belonging to the Nsukka and Mamu formations. The Nsukka formation which is called the Upper Coal Measure bears sandstone, shale and coal, while the underlying Mamu formation which is similar in composition with the Nsukka offers a higher frequency of coal occurrence.

THEORY

Maillet (1947) expounded the fundamental theory behind the resistivity method and the theory has been adequate covered by Keller and Frischknecht (1966), Grant and West (1965), and Bhattacharya and Partra (1968).
Feynman et al. (1965) express the Maxwell's equation for earth materials having dielectric and magnetic properties as:

$$\nabla \times \underline{H} = \underline{J} + \partial D / \partial t \tag{1}$$

$$\nabla \times E = -\partial B / \partial t \tag{2}$$

$$\nabla \cdot \underline{B} = 0 \tag{3}$$

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Table 1. Iventory of sampling points distribution at the study area, Iyakpi, South Ibie.

S/N	Description of item	Position		Elevation (ft)
		Latitude	Longitude	
1	VES 1	07^0 03.079’	06^0 17.849’	613
2	VES 2	07^0 03.079’	06^0 17.677’	637

$$\nabla \cdot \underline{D} = Q \tag{4}$$

Where H = magnetic field = $\dfrac{B - \mu_0 M}{\mu_0}$

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

that is, $\nabla \cdot \nabla \times H = \nabla \cdot J + \nabla \cdot {}^{\partial D}/_{\partial t}$

But the divergence of a curl is zero

$$\nabla \cdot J - \nabla {}^{\partial D}/_{\partial t} = 0$$

$$\therefore \nabla \cdot J = -{}^{\partial}/_{\partial t} \nabla D \tag{5}$$

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

$$\nabla \cdot \underline{J} = -{}^{\partial}/_{\partial t} Q \tag{6}$$

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) becomes:

$$\nabla \times \underline{E} = 0 \tag{7}$$

$$\nabla \cdot \underline{J} = 0 \tag{8}$$

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

$$\underline{E} = -\nabla V \tag{9}$$

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:

$$J = \sigma E \tag{10}$$

This proportionality constant is called conductivity.

It must be noted that for an isotropic medium, the conductivity will be a scalar quantity so that J and E will be in the same direction. In general, J and 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 and j may be any of the x, y or z spatial directions in a rectangular co-ordinate system. Ohm’s law becomes:

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

$$\begin{bmatrix} J_x \\ J_y \\ J_z \end{bmatrix} = \begin{bmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{xz} \\ \sigma_{yx} & \sigma_{yy} & \sigma_{yz} \\ \sigma_{zx} & \sigma_{zy} & \sigma_{zz} \end{bmatrix} \begin{bmatrix} E_x \\ E_y \\ E_z \end{bmatrix} \tag{11}$$

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

$$\nabla(\sigma_\eta \nabla V) = 0 \tag{12}$$

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

$$\nabla^2 V = 0 \tag{13}$$

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.

B = Magnetic flux density,
T = time,
μ_0 = Permeability of free space,
$\underline{P}$ = Polarization,
$\underline{M}$ = Magnetization,
Q = electric charge density.
$\underline{J}$ = Current density,
$\underline{E}$ = Electric field strength
$\underline{D}$ = Electric displacement = $\varepsilon_0 \underline{E} + \underline{P}$
ε_0 = Permittivity of free space

EXPERIMENT

In this research work, the schlumberger array in electrical resistivity survey was adopted. The basic field equipment for this study is the ABEM Terrameter SAS 300B which displays apparent resistivity values digitally as computed from ohm’s law. It is powered by a 12.5V DC power source. Other accessories to the terrameter includes the booster, four metal electrodes, cables for current and potential electrodes, harmers (3), measuring tapes, walking talking or phones for very long spread (Asokhia, 1995). Location fixing and topographical heightening of the sampling points was achieved by means of twelve channel global positioning system (GPS) set – the ‘GARMIN GPS 12’ (Table 1). In this configuration (Figure 1) the four electrodes are positioned symmetrically along a straight line, the current electrodes on the outside and the potential electrodes on the inside. To change the depth range of the measurements, the current electrodes are displaced outwards while the potential electrodes in general, are left at the same position.

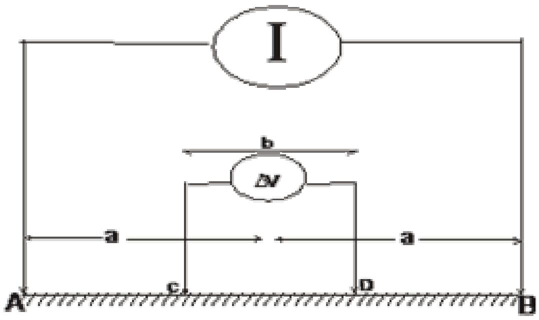

Figure 1. Schlumberger array.

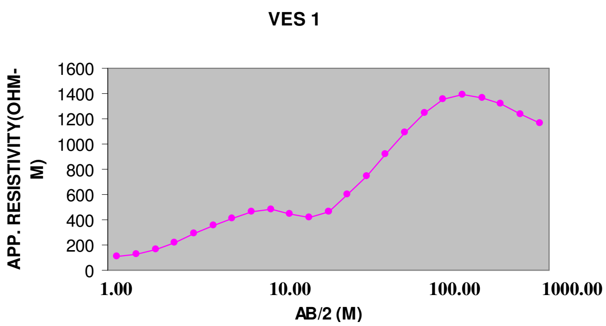

Figure 2. Resistivity sounding interpretation for VES 1.

When the ratio of the distance between the current electrodes to that between the potential electrodes becomes too large, the potential electrodes must also be displaced outwards otherwise the potential difference becomes too small to be measured with sufficient accuracy (Koefoed, 1979).

Measurements of current and potential electrode positions are marked such that AB/2 ≥ MN/2. Where AB/2 = Current electrode spacing and MN/2 = Potential electrode spacing.

Generally, the arrangement consists of a pair of current electrodes and a pair of potential electrodes. These are driven into the earth in a straight line to make a good contact with the earth. The current electrode spacing are expanded over a range of values for measurements in the field. The values of AB/2 increases as the measurements progresses while the potential electrodes separations are guided accordingly. The potential electrodes are kept at small separations relative to the current electrodes separations (Milson, 1939). One of the major advantages this method has over other methods is that only the current electrodes need to be shifted to new position for most readings while potential electrodes are kept constant for up to three or four readings (Reinhard, 1974). During the exploration work (field work) taking a sounding, the ABEM Terrameter SAS 300B (Self Averaging System) performs automatic recording of both voltage and current, stacks the results, computes the resistance in real time and digitally displays it. (Dobrin, et al., 1976).

From the theory we have that the potential at C due to A is

$$V_c = \frac{\rho I}{2\pi}\left\{\frac{1}{a-b/2} - \frac{1}{a+b/2}\right\} \tag{13}$$

Where

$a \Rightarrow$ midpoint $\Rightarrow$ distance between the current electrodes and station.

b $\Rightarrow$ distance between potential electrodes

$\rho \Rightarrow$ layer resistivity

The potential at D due to A becomes

$$V_D = \frac{\rho I}{2\pi}\left\{\frac{1}{a+b/2} - \frac{1}{a-b/2}\right\} \tag{14}$$

The potential difference dV between the two potentials is therefore given by

$dV = V_C - V_D$

$$\therefore dV = \frac{\rho I}{2\pi}\left\{\frac{1}{a-b/2} - \frac{1}{a+b/2}\right\} - \frac{\rho I}{2\pi}\left\{\frac{1}{a+b/2} - \frac{1}{a-b/2}\right\}$$

$$dV = \frac{\rho I}{2\pi}\left\{\frac{2}{a-b/2} - \frac{2}{a+b/2}\right\}$$

$$dV = \frac{\rho I}{2\pi}\left(\frac{8b}{4a^2-b^2}\right) \tag{15}$$

The apparent resistivity value is the product of the geometric factor and the resistance recorded in the resistivity meter. In each station, geoelectric soundings and apparent resistivity values was obtained by expanding the current electrode spacing after each reading as required by Schlumberger array for deeper penetration into the earth and structural responses. The geometric factor, K, for Schlumberger configuration was used.

$$K = \frac{\pi}{2}\left\{\frac{(AB/2)^2 - (MN/2)^2}{MN/2}\right\}$$

$$\therefore K = \pi CD\left\{\left(\frac{L}{CD}\right)^2 - 0.25\right\} \tag{16}$$

$$L = 2(AB/2)$$

The interpretation of the field data was by the qualitative process of plotting of the resistivity field curve to ensure data reliability (Asokhia et al., 2000). The observed field data are fed into the computer, while theoretical resistivity models are generated by means of appropriate computer program that is given a set of layer parameters, using a 9- point digital linear filter (Koefoed, 1979). Automatic iterative interpretation, following the main ideas of Zohdy (1989) was employed in the final selection of layer para-meters. Here the number of geolectric layers and their corres-ponding specific resistivities are first taken to be equal to the number of measurement points and the difference of adjacent current electrode spacing respectively. Layers parameters are consequently modified in iterative manner until subsequent iteration yields no improvement on the root mean square (RMS) error. The resulting layer parameters are now given geologic interpretation.

RESULTS AND DISCUSSION

The results of interpreted data for VES 1 and VES 2 of the study area are respectively presented in Figure 2 and Figure 3. Both VES curves present a basic ascending-bell-bowl-ascending (AKHA) type-curve. VES 1 and 2 showed that the initial data points of the first ascending branch indicate a bowl (H) shape and the last few data

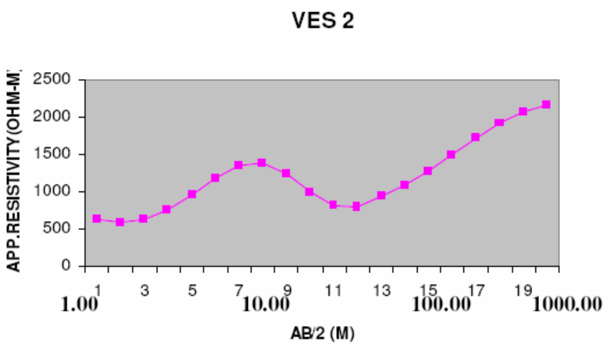

Figure 3. Resistivity sounding interpretation for VES 2.

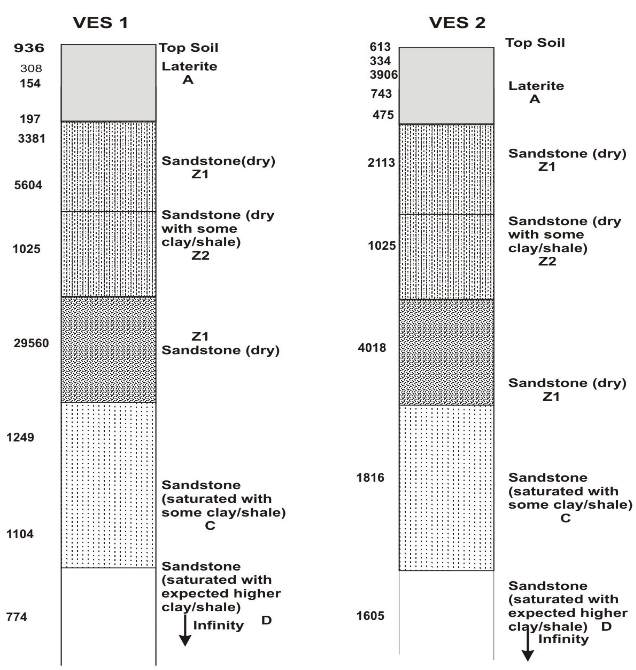

Figure 4. Lithological cross section for the VES (1 and 2).

points of the final ascending branch indicate a bell (K) shape. Computer interpretation of the VES curves resolved twelve (12) geoelectric layers for VES 1 and nine (9) geoelectric layers for VES2. Figure 1 showed the geological interpretation of the resolved geoelectric layers. Four basic depth intervals of hydrogeological relevance were identified for the site in the study area. The depth interval A corresponds to dry lateritic sand. It consists of a thin layer of topsoil surface sand (about 1m) and a dry top resistive material which becomes conductive and clayey at the base. Interpreted maximum thickness for this lateritic layering unit is 35 m. The next underlying depth interval Z, is assigned dry sandstone (Z_1 depth zone) as shown in Figure 1. A resistivity lowering layer in the middle section was observed (Z_2). This seems to support possible presence of interbedding conducting materials (e.g. clay) within the dry sandstone layering unit. The immediately underlying resistive layer depth zone (C) corresponds to the existing saturated aquifer in the study area. This is assigned sandstone status with a high potential for bearing clay/shale interbedly unit. This lies on an interpreted depth of about 190 to 196 m with an interpreted average of about 60 m. The existing substratum layer A is deemed to have similar materials composition at C, but the concentration and the frequency of occurrence of the clay/shale body increases

From the interpreted depth intervals of A and Z, lateritic hard horizon that could pose significant resistance to drilling should be expected. Also to be expected is the development of long circulation behaviour especially with Z interval maximum success will be achieved for a borehole upon granite for drill penetration of the interpreted saturated aquifer depth zone C. Therefore, a maximum drill of 260 m is advised for a borehole in the study area (Figure 4).

Conclusion

The geophysical investigation results of the electrical resistivity method in the study area agree with the possibility of having a successful borehole in the area. The subsurface geologic materials in the study area are mainly sand, sandstone and shale/clay (Figure 1). From the computer interpretation, the depth to top of the existing aquifer in the study area is 195 m (640 ft). Therefore a maximum drill depth of 260 m (865.80 ft) is advised. What should be advised also to ensure accurate litho-logging and proper documentation is to have an effective professional supervision. A down-hole geophysical logging of the drill hole should be conducted to enhance or facilitate well design and completion processes for optimization of resulting borehole yield. It is also proper to carry out water quality analysis and complete borehole documentation which should be in accordance with known professional practice.

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