Lithological Assessment from Geophysical Survey in Amai in Delta State, Nigeria.

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Abstract: The Schlumberger electrode configuration for vertical electrical sounding was utilized to survey Amai and its environs in an attempt to define and analyze the geoelectrical structure and the geologic variation within the subsurface of the area. Five vertical electrical sounding (VES) stations were surveyed using the ABEM Terrameter SAS 1000AB. The maximum current electrodes separation lies between 500m and 800m depending on accessibility. Data collected were curve-matched before computer iteration and the results show a well defined geoelectric structure in terms of the lithological structure of clayey sand, fine sand and medium grained sand. A four to five geoelectric layers were obtained with thicknesses ranging from 1.0 to 708.0m and resistivities from 93.4 Ωm to a maximum of 5850.50 Ωm.

Key words: Geoelectric section, computer iteration, curve-matching, current electrodes, potential electrodes lithology.

INTRODUCTION

To meet the objectives of the project, geophysical methods such as vertical electrical sounding (VES) and Spontaneous Potential (SP) log were used. This was necessary since the geologic exposure is not good enough, except for expensive drilling. Geophysics is the only means whereby the desired subsurface information could be obtained.

The success of geophysical method largely depends upon the presence of significant and detectable contrasts in the earth’s physical properties (Overneeren, 1981). In Amai areas, good contrasts in electrical resistivity were expected between clayey and sandy layers, between water-bearing and dry layers or impervious bedrocks and between formations bearing fresh water and saline water.

A good attempt at the characterization of changes in the lithology will no doubt enhance the mapping of rock units, stratigraphic correlation and thus improve on the existing known geology of this area (Okwueze, et al, 1995).

The VES is a technique used extensively in geotechnical surveys to determine over-burden thickness and in hydrogeology to define horizontal zones of porous strata.

The study attempts at having a clear picture and depth of the lithological formation and the aquifer levels. This will also help in the location of area with high aquifer potential for sitting of boreholes for economic purposes. Vertical electrical sounding was chosen for the purpose of this survey because the instrument is simple, field logistics are easy and straight forward and the analysis of data is economical and less tedious than other methods (Zhody, et al, 1974, Van Overneeren 1989). Olorunfemi, et al (1999), Asseez (1989), Ayolabi (2005) and Todd (1980) are amongst the reports in literature on this subject.

Theoretical Analysis:

If the ground is homogeneous, the apparent resistivity is equivalent to actual resistivity. The potential difference between two points due to a current applied through a dipolar source at the earth’s surface is as shown in figure 1.

If \( V_1 \) and \( V_2 \) are the potentials at \( p_1 \) arising from the surface electrodes \( C_1 \) and \( C_2 \) and if \( V_3 \) and \( V_4 \) are the potentials arising from \( C_1 \) and \( C_2 \) the potential difference is

\[
\Delta V = (V_1 + V_2) - (V_3 + V_4)
\]
Electrodes on a Two Layered Earth:

Consider a two-layered earth (Fig. 2) on which an electrode \( C \) is grounded. Potential in the upper and lower layers respectively consist of primary and secondary parts.

\[
V' = V_p + V_{s1}
\]

\[
V'' = V_p + V_{s2}
\]

Primary potential \( V_p \)
Secondary potential induced in the first layer \( V_{s1} \)
Secondary potential induced in the secondary layer \( V_{s2} \)

Taking primary potential \( V_p \) as due to a grounded electrode on a uniform earth of resistivity \( \rho_1 \) equal to that of the upper layer.

\[
V_p = \frac{I \rho_1}{2\pi r_1} = \frac{I \rho_1}{2\pi \left(x^2 + y^2 + z^2\right)^{\frac{1}{2}}} = \frac{I \rho_1}{2\pi} \left(z^2 + r^2\right)^{-\frac{1}{2}}
\]

where \( r^2 = x^2 + y^2 \)

\[
\left(z^2 + r^2\right)^{-\frac{1}{2}} = \int_0^\infty J_0(\lambda r)e^{-\lambda z}d\lambda
\]

The right hand side of the equation is the Laplace transformation of the Zeroth order which is Bessel function of the first kind.
$V_p = \frac{I \rho}{2\pi} \int_0^\infty J_1(\lambda r) e^{-\lambda z} d\lambda$  

(4)

Seek secondary potential in the form

$$V_{s_1} = \int_0^\infty \left[ f_1(\lambda)e^{-\lambda z} + g_1(\lambda)e^{\lambda z} \right] J_0(\lambda r) d\lambda$$  

(5)

$$V_{s_2} = \int_0^\infty \left[ f_2(\lambda)e^{-\lambda z} + g_2(\lambda)e^{\lambda z} \right] J_0(\lambda r) d\lambda$$  

(6)

Problem reduces to the evaluation of the eigen function $f_1(\lambda), f_2(\lambda), g_1(\lambda)$ and $g_2(\lambda)$ using the boundary conditions.

**Boundary Conditions:**

The first boundary condition is continuity of $J$ across the interface bounding the half-space. Since normal current density in air is zero, the normal $J_z$ must be zero in the medium at the interface where $z = 0$.

$$J_z = 0 \text{ or } gE_z = 0 \text{ or }$$

$$E_z = -\frac{\partial V}{\partial z} = 0 \text{ at } z = 0$$

$$\Rightarrow f_1 = g_1$$

Secondary boundary condition is

$$V_{s_1} \to 0 \text{ as } z \to \infty$$

$$g_z = 0$$

Continuity of potential across boundary between region 1 and medium 2.

$$V' = V'' \text{ at } z = d_1$$  

(7)

Continuity of normal current density across boundary between region 1 and medium 2.

$$\frac{1}{\rho_1} \frac{\partial V'}{\partial z} = \frac{1}{\rho_2} \frac{\partial V''}{\partial z} \text{ at } z = d_1$$  

(8)

From equation (7),

$$f_1(\lambda)[e^{-\lambda d_1} + e^{\lambda d_1}] = f_2(\lambda)e^{-\lambda d_1}$$  

(9)

From equation (8)
Solving equations (9) and (10) simultaneously, we get

\[
f_1(\lambda) = \frac{I \rho_1}{2\pi} \left( \frac{-U_i e^{-2\lambda d_i}}{1 + U_i e^{-2\lambda d_i}} \right)
\]

\[
f_2(\lambda) = \frac{I \rho_1}{2\pi} \left( \frac{-U_i \{e^{-2\lambda d_i} + 1\}}{1 + U_i e^{-2\lambda d_i}} \right)
\]

where \( U_i = \frac{\rho_1 - \rho_2}{\rho_1 + \rho_2} \)

In practice, we measure potential only at the earth’s surface in medium 1. Because we normally measure potentials only at the surface of medium 1, we need only consider the eigen function \( f_i(\lambda) \), henceforth substitute equation (11) into (5), and get \( z = 0 \).

The secondary potential is

\[
V_{S_i} = \frac{I \rho_1}{2\pi} \int_0^\infty \frac{-2U_i e^{-2\lambda d_i}}{1 + U_i e^{-2\lambda d_i}} J_0(\lambda r) d\lambda
\]

\[
V_p = \frac{I \rho_1}{2\pi} \int_0^\infty J_0(\lambda r) d\lambda
\]

Add this to the primary potential given by equation (4) with \( z = 0 \) to get the total potential

\[
V^1 = \frac{I \rho_1}{2\pi} \int_0^\infty \frac{1 - U_i e^{-2\lambda d_i}}{1 + U_i e^{-2\lambda d_i}} J_0(\lambda r) d\lambda
\]

Potential gradient observed between a pair of electrodes \( p_1 \) and \( p_2 \) due to current transferred into a two-layered earth through a pair of current electrodes \( C_1 \) and \( C_2 \) is

\[
\Delta V = (V^1_1 + V^1_2) - (V^1_3 + V^1_4)
\]

\[
V^1_1 = \frac{I \rho_1}{2\pi} \left( \frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4} \right)
\]

\[
V^1 = \frac{I \rho_1}{2\pi} \int_0^\infty \frac{1 - U_i e^{-2\lambda d_i}}{1 + U_i e^{-2\lambda d_i}} \left[ J_0(\lambda r_1) - J_0(\lambda r_2) - J_0(\lambda r_3) + J_0(\lambda r_4) \right] d\lambda
\]
Fig. 3: Shows the potential gradient observed between electrodes $p_1$ and $p_2$ due to a pair of current electrodes $C_1$ and $C_2$.

A Binomial expansion of the denominator of $f_i(\lambda)$, allows us to write equation 11 as

$$f_i(\lambda) = \frac{1}{2\pi} \left\{ -U_1 e^{-2\lambda d_i} + U_2 e^{2\lambda d_i} - U_1^3 e^{-6\lambda d_i} + \cdots \right\}$$

$$= \frac{1}{2\pi} \sum_{n=1}^{\infty} (-U_1)^n e^{-2nd_i\lambda}$$

(14)

Then the secondary potential (eqn. 5) may be written for $z = 0$ (i.e. at surface of the earth) as

$$V_{S_i} = \frac{1}{2\pi} \int_0^\infty \sum_{n=1}^{\infty} (-U_1)^n e^{-2nd_i\lambda} J_0(\lambda r) d\lambda$$

$$= \frac{1}{2\pi} \sum_{n=1}^{\infty} (-U_1)^n \int_0^\infty e^{2nd_i\lambda} J_0(\lambda r) d\lambda$$

$$= \frac{1}{2\pi} \sum_{n=1}^{\infty} (-U_1)^n \frac{1}{[r^2 + (2nd_i)^2]^{1/2}}$$

(15)

Combining this potential with the primary potential given by equation (3) at $z = 0$ to obtain the total potential observed at the surface of the earth

$$V^i = V_p + V_{S_i}$$

$$= \frac{1}{2\pi} \left[ \frac{1}{r} + \sum_{n=1}^{\infty} \left\{ \frac{(-U_1)^n}{r^2 + (2nd_i)^2} \right\}^{1/2} \right]$$

(16)

Potential gradient observed between a pair of electrodes $p_1$ and $p_2$ due to current transferred to a z-layered earth through a pair of current electrodes $C_1$ and $C_2$, the potential difference is

$$\Delta V = (V_1 + V_2) - (V_3 + V_4)$$
Electrodes on a Three Layered Earth:

This is as shown in figure 4 below.

Fig. 4: Electrodes on three layered earth.

The potential $V'$ and $V''$ in the first two layers are as before

$V' = V_p + V_{S_1}$

$V'' = V_p + V_{S_2}$

In the third layer

$V''' = V_p + V_{S_3}$

The four potentials $V_p, V_{S_1}, V_{S_2}, V_{S_3}$ may be as before

$V_p = \frac{I \rho}{2\pi} \int_0^\infty e^{-\lambda z} J_0(\lambda r) d\lambda$  \hspace{1cm} (17)
\begin{align*}
V_{S_1} &= \int_0^\infty \left[ f_1(\lambda) e^{-\lambda z} + g_1(\lambda) e^{\lambda z} \right] J_0(\lambda r) d\lambda \\
V_{S_2} &= \int_0^\infty \left[ f_2(\lambda) e^{-\lambda z} + g_2(\lambda) e^{\lambda z} \right] J_0(\lambda r) d\lambda \\
V_{S_3} &= \int_0^\infty \left[ f_3(\lambda) e^{-\lambda z} + g_3(\lambda) e^{\lambda z} \right] J_0(\lambda r) d\lambda
\end{align*}

Solving for the eigen function \( f_1(\lambda), f_2(\lambda), f_3(\lambda), g_1(\lambda), g_2(\lambda), \) \( g_3(\lambda) \) by using the appropriate boundary conditions. The continuity of \( J_z \) at \( z = 0 \) again ensures that \( f_1 = g_1 \) (as before).

The condition \( V_{S_3} \to 0 \) as \( z \to \infty \) provides \( g_3 = 0 \). The unknown reduced to four boundary conditions.

Continuity of potentials at sequence between layer 1 and 2
\begin{align*}
V' &= V" \text{ at } z = d_1 \\
V' &= V" \text{ at } z = d_1 + d_2
\end{align*}

Continuity of current density
From equations (17) and (18)
\[ \frac{1}{\rho_1} \frac{\partial V'}{\partial z} = \frac{1}{\rho_2} \frac{\partial V"}{\partial z} \text{ at } Z = d_1 \]

From equations (18) and (19)
\[ \frac{1}{\rho_2} \frac{\partial V"}{\partial z} = \frac{1}{\rho_3} \frac{\partial V"'}{\partial z} \text{ at } z = d_1 + d_2 \]

Using these, we get 4 simultaneous equations with 4 unknowns \( f_1(\lambda), f_2(\lambda), g_2(\lambda), f_3(\lambda) \). Solve using Crammer’s rule and substitute eigen function values in equations (18) to find the secondary potential at the surface of the earth. Add this \( V_{S_1} \) to the primary potential for \( z = 0 \) and obtain, that is, use \( f_1(\lambda) \) to obtain \( V_{S_1} \).

\[ V' = V_p + V_{S_1} \text{ at } z = 0. \]

This implies that
$$V' = \frac{I \rho_1}{2\pi} \int_{0}^{\infty} \frac{1 - U(\lambda) e^{-2\lambda d_1}}{1 + U(\lambda) e^{-2\lambda d_1}} J_0(\lambda r) \, dr$$

where

$$U(\lambda) = \frac{\rho_1 - \rho_2}{\rho_1 + \rho_2} \left( \frac{1 - U_2 e^{-2\lambda d_2}}{1 + U_2 e^{-2\lambda d_2}} \right)$$

and

$$U_2 = \frac{\rho_2 - \rho_3}{\rho_2 + \rho_3}$$

Electrode on an N-layered Earth:

The potential at the surface of a two-layered earth case is

$$V' = \frac{I \rho_1}{2\pi} \int_{0}^{\infty} \frac{1 - U_1 e^{-2\lambda d_1}}{1 + U_1 e^{-2\lambda d_1}} J_0(\lambda r) \, d\lambda$$

This can be written as

$$V' = \frac{I \rho_1}{2\pi} \int_{0}^{\infty} k_{12} (\lambda) J_0(\lambda r) \, d\lambda$$

where the kernel of integral is $k$

$$k_{12} = \frac{1 - U_{12} e^{-2\lambda d_1}}{1 + U_{12} e^{-2\lambda d_1}}$$

where

$$U_{12} = \frac{\rho_1 - \rho_2}{\rho_1 + \rho_2}$$

Similarly, the potential at the surface of a three-layered earth may be written as

$$V' = \frac{I \rho_1}{2\pi} \int_{0}^{\infty} k_{123} (\lambda) J_0(\lambda r) \, d\lambda$$

where

$$k_{123} = \frac{1 - U_{123} e^{-2\lambda d_1}}{1 + U_{123} e^{-2\lambda d_1}}$$

$$U_{123} = \frac{\rho_1 - \rho_2 k_{12}}{\rho_1 + \rho_2 k_{12}}$$

$$k_{23} = \frac{1 - U_{23} e^{-2\lambda d_2}}{1 + U_{23} e^{-2\lambda d_2}}$$
\[ U_{23} = \frac{\rho_2 - \rho_3}{\rho_2 + \rho_3} \]

By inference, the potential at the surface of an \( n \)-layer earth is

\[ V' = \frac{I \rho_i}{2\pi} \int_0^\infty k_{12} \frac{1}{n} J_0(\lambda r) d\lambda \]

where \( k_{12} = \frac{1 - U_{12}}{1 + U_{12}} \rho^{-2\lambda d_i} \), etc.

Similarly, we can get \( \Delta V \) in the same way.

**Location:**

Amai, a town in Ukwuani Local Government Area of Delta State, Nigeria is located between longitude 5°30' and 6°00' and latitude 6°00' and 6°20'E. It is bounded on the west by Obiaruku, to the east by Ogwume, on the south by Ezionu and north by Obiaruku. The population of the area is increasing because of the new institution, Novena University, a privately owned institution. The area has a flat terrain with a small stream where the inhabitants get their water for domestic use. It experiences the equatorial hot and wet climate with almost uniform temperature throughout the year. The vegetation is the rainforest zone. Figures 5, 6 and 7 show the study area, the contour and the topography of the area respectively.

**Field Work:**

Vertical electrical sounding (VES) using the Schlumberger electrode configuration was adopted. A total of 145 vertical electrical sounding were carried out at five different locations. The total current electrodes spread varied from minimum of 450m to a maximum of 800m depending on the accessibility of the roads. The entire survey was carried out making sure that all the transverses were cut to have a straight path.

The field procedure in the Schlumberger electrode array system is to expand the electrodes successfully while the potential electrodes remain fixed. This process yields a rapidly decreasing potential difference across the potential electrodes which ultimately exceeds the measuring capabilities of the instrument (Egbai and Asokhai, 1998). At this point, a new value for potential electrode separation is selected typically 2 to 4 times larger that the preceding value and survey is continued. The ABEM Terrameter SAS 1000AB with an inbuilt booster was used for the data acquisition. The booster helps to inject more current into the ground for proper penetration.

**Fig. 5:** Base Map of study area.
Fig. 6: VES 1 (Opposite Central Mosque, Amai).

Fig. 7: VES 2 (Along Ogume Road).

Fig. 8: VES 3 (Along Abbi-Orogun Road, Amai).
RESULTS AND DISCUSSION

The data obtained from the field were plotted using apparent resistivity values versus half current electrode separation distances to obtain VES curves. The sounding curves were analyzed first by partial curve-matching method. The results of the curve-matching were used for qualitative interpretation through computer iteration to obtain the layer resistivities and the thickness parameters. The summary of iterated values are shown in table 1.

The iterated curves for the five locations are as shown in figures 6 to 10. Figure 11 shows the geoelectrical section for the five locations.

The curves obtained were of KA, HA, HKQ, HA and AKQ for VES 1, 2, 3, 4 and 5 respectively. The result of the thickness and resistivities values obtained from the partial curve-matching were improved upon by a computer iteration method using the Resist software of Vander Velphen, 1988.

In VES 1 location, the first and second layer is made up of clayey sand and varies in depth from 0.8m to 3.4m. The third layer is made up of fine sand with depth varying from 3.4m to 16.3m, while the fourth layer is made of medium grained sand varying from 16.3m to infinity.
Table 1: Summary of iterated values

<table>
<thead>
<tr>
<th>VES</th>
<th>Layers</th>
<th>Resistivity (Ωm)</th>
<th>Thickness (m)</th>
<th>Depth(m)</th>
<th>Lithology</th>
<th>Curve</th>
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<tbody>
<tr>
<td>I</td>
<td>i</td>
<td>212.1</td>
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<td>0.8</td>
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<td>KA</td>
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<tr>
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<td>2.6</td>
<td>3.4</td>
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<td></td>
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<tr>
<td></td>
<td>iii</td>
<td>135</td>
<td>12.9</td>
<td>16.3</td>
<td>Fine Sand</td>
<td></td>
</tr>
<tr>
<td></td>
<td>iv</td>
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<td>$\rho_1 &lt; \rho_2 &gt; \rho_3 &lt; \rho_4$</td>
</tr>
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<td>i</td>
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<td>1</td>
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<tr>
<td></td>
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<td>Medium Grain Sand</td>
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</table>

For VES II, the layers are made up of clayey sand, fine sand and medium grained sand varying from 0m to 1.0m, 1.0 m to 3.7m and from 3.7m to 21.0m till infinity respectively.

For VES III, IV and V, the results are as shown in table 1. The lithological set ups are equally shown in the table. The configuration of this is got from series of borehole results from the area under study.

![Fig. 11: The Geoelectric Structure of Amai and Environs](image)

**Conclusion:**

The results of VES, geoelectric section and borehole measurement and assessment, it could be suggested with high certainty that pure clay could be got from Amai while a confined aquifer can be found between 18m and 30m in depth.

**ACKNOWLEDGMENT**

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