# Lithological Investigation at Tombia and Opolo Using Vertical Electrical Soundings and Pseudo Tomogram

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***Abstract*:-Vertical electrical soundings (VES) was carried out in Opolo and Tombia all in Yenagoa local government area, Bayelsa state, Nigeria to understand the resistivity distribution of its subsurface which serves as a tool in investigating subsurface lithology. All VES sounding were stacked together to generate 1D pseudo tomogram and was subsequently interpreted. The interpreted VES curve results shows that Opolo consists of three layers within the depth of investigation. Sandy clay with mixture of silt make up the first layer (Top layer) with resistance value ranging from 24-63Ωm. The second layer is made up of thick clay with very low resistivity values ranging from 3-19Ωm. The third layer is sandyclay with its resistance value ranging from 26-727Ωm.Tombia also reveals that the area is in three layers within the depth of investigation. Sandy clay with a mixture of fine sand made up the first layer (Top soil) with its resistance values ranging from 40-1194Ωm. The second layer is made up of fine sand with resistivity value ranging from 475-5285Ωm. The third layer is made up of sandy clay/sand with its resistance value ranging from 24-28943Ωm.The results of the 1D pseudo tomogram also reveals that Tombia and Opolo consists of three layers within the depth of investigation and pseudo tomograms serves as a basis tool for interpreting lithology and identifying lithological boundaries for the subsurface.**

***Keywords:* VES, Tomogram, 1D, Resistivity, Yenagoa.**

## I. INTRODUCTION

Geophysical Exploration is a fundamental part of geophysics in geosciences which gives us an insight of subsurface features based on the physical properties of the earth. With this study, scientists and researchers have been able to determine different changes in depth, such as rheological behavior, electrical and magnetic properties, among others, thus allowing greater knowledge about the structure of the land. Geo-electric methods are widely used in engineering research, geophysics, geology and hydrology, geological engineering and environmental studies. Some of them have been developed to study complex heterogeneous structures. Finite differences (FD), finite elements (FE), integral equations, and analytical methods and approaches were developed to find 2D / 3D structures. 1D approximation method is often used to solve forward and inverse problems as explained by Koefoed and Mallick (1979).

Rapid advances in computer software and other numerical modeling techniques are increasing the use of geophysical methods for groundwater researches and water quality assessment. The use of vertical electrical sounding (VES) has become very common in the search for quality groundwater due to the simplicity of the technology. The aim of the geophysical method is to capture the surface effect created by the flow of current in the ground for various geophysical studies such as mineral exploration, archeological investigation, exploration, and geological mapping. Vertical Electrical Sounding is said to be a very good alternative for the determination of underground resistivity and lithology (Meindinyo et al., 2017).

Electrical Resistivity Tomography is an advanced geophysics method used to determine the subsurface's resistivity distribution by making measurements on the ground surface (Ehirim et al., 2016). Tomographic inversion is to reconstruct the geological model that offers synthetic data matching with observed data. Therefore, tomographic inversion is often defined as the optimization of data fittingness with the regularization of the model.

In this study, VES was acquired and interpreted. Also, a 1D pseudo tomogram was interpreted to understand the tomogram and the lithology of the subsurface under investigation.

## II. STUDY AREA

Yenagoa is the capital city and commercial hub of Bayelsa State. It is located in Yenagoa Local Government Area, which is about 706 km² in size and had a population of about 266,008 at the 2006 census with longitudes of 006o 05´ and 00 6o 025´ East of the prime meridian and latitudes of 04o 23.3´ and 04o 38.2´ North of the equator. The geographical area is located in the coastal zone of the Niger Delta (Figure. 1), and the land surface is relatively flat and slopes very gently seawards. Its tropical rain forest climate is characterized by the rainy season and dry season. From April to October occurs its rainy season and the dry season lasts between November and March. The temperature is between 25oC and 32oC as summarized by Oborie and Nwankwoala (2012).

The study area is located within freshwater swamps, deltas, alluvial sediments and the Mediterranean Sea of the Niger Delta. The surface thickness ranges from 5 to 12 m, and the permeability of the aquitard is very variable since the ratio of clay, silt, and sand is different. During the rainy season, water increases significantly, and in some cases the  and falls into a flood.

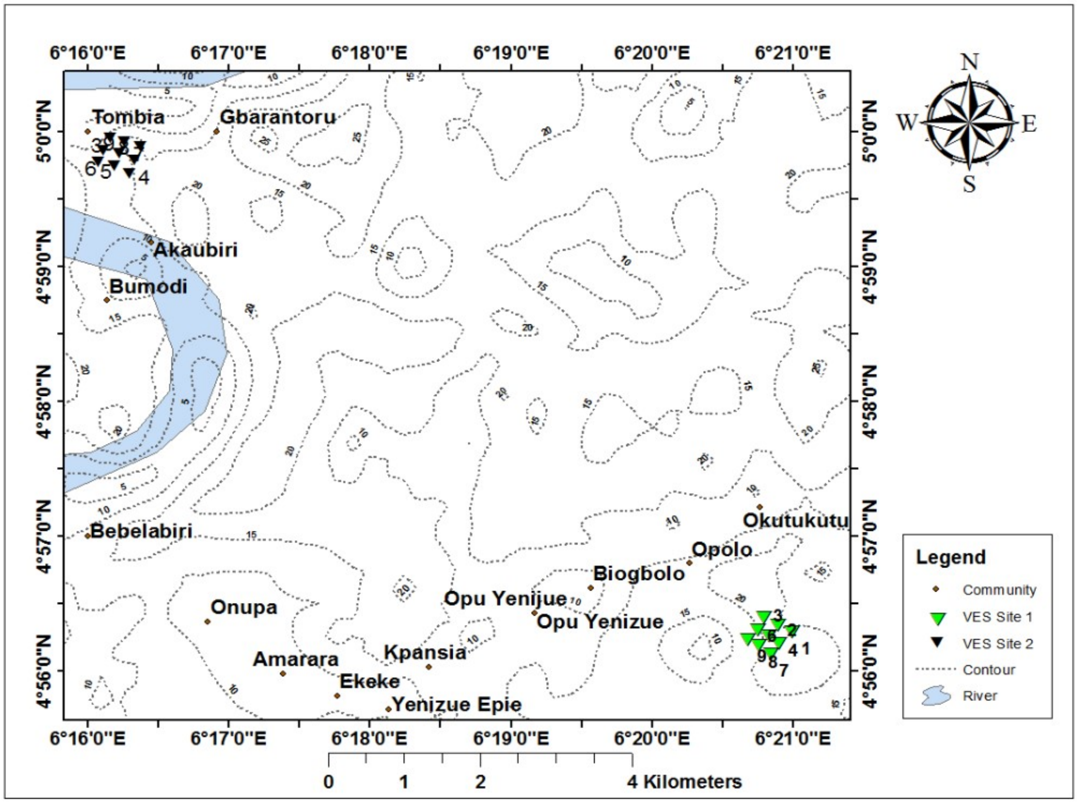


Fig.1: Map of the Study area showing VES points

## III. MATERIALS AND METHODS

Vertical Electrical Sounding (VES) using Schlumberger array was carried out in two locations, with the current electrode spacing of $\frac{AB}{2}$=80m that is, the largest current electrode spacing AB used was 160m. Nine VES profiles were taken in the first location (Opolo) and another Nine VES profile was taken in the second location (Tombia village).

In carrying out the Schlumberger array, four co-linear electrodes are needed. The two external electrodes are current electrodes and the two internal electrodes are potential electrodes (receiving elements) (Figure. 2). The electrode potential is placed at a short distance from the center of the electrode array, and also, less than one-fifth of the distance between the current electrodes. The distance of the current electrode was increased during the test, but the potential electrode remains in the same position for a while and later was increased as well when the observed voltage becomes too small to measure. The tool used in this study is the Abem Terrameter SAS 1000, a sophisticated tool that automatically displays the resistance value of each VES point on a digital display screen and these values were written down on a book provided during the fieldwork.

First, the geometric K factor was calculated for all the electrode distance using the formula $K = \pi\frac{L^2}{2l} - \frac{b}{2}$, for Schlumberger array with MN = 2L and $\frac{AB}{2} = L$. The K factor values obtained were then used to multiply the resistance values to obtain the apparent resistivity, ρa, values. Then the apparent resistivity, ρa, values were plotted against the electrode spacing ($\frac{AB}{2}$) on a log-log scale to obtain the VES sounding curves using a computer software IPI2win+IP.

The field curves were at first interpreted through partial curve matching techniques, using theoretically calculated master curves, in conjunction with the auxiliary curves of A, Q, K and H types. This information (layer parameters) was then used to interpret the sounding data through a 1-D inversion technique (i.e. ipi2win, Interpex Limited, Golden, Co).

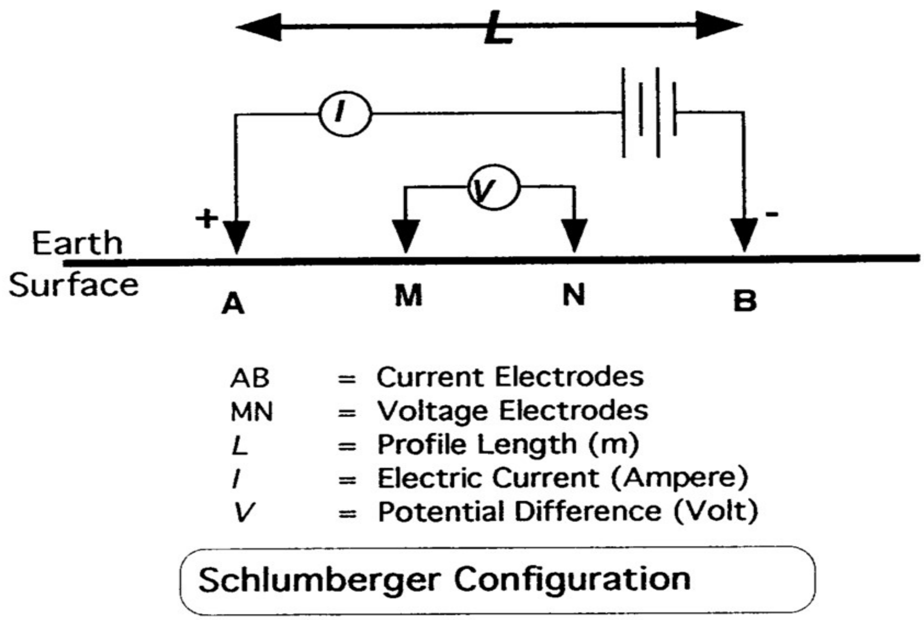


Fig.2: The Full-Schlumberger Array.

Interpex Inversion technique is a graphical interactive front and back simulation program. The current resistance curve (apparent resistivity curve) is determined using a linear filter. Inverse modeling allows you to get the model that best fits the data in the least squares sense which follows an inversion procedure. The best-fitted model is obtained by the geo-electrical point with an error rate from 1 to 2% for the upper and lower bound models. Then, ZONDIP was used to create a pseudo-partition or tomogram after stacking all the profiles together. The goal of the ZONDIP program is to determine the resistivity of a rectangular block and create a pseudo-section that corresponds to the actual measurement.

## IV. RESULTS AND DISCUSSIONS

In this work, eighteen geo-electrical profile was acquired in two locations i.e nine in Opolo and nine in Tombia village and the electrical resistivity soundings were carried out using Schlumberger configuration. Figure 3 shows that the resistivity models at the two sites – Opolo and Tombia Fig. 3 (a and c) have K and H curves with three geological layers within our depth of investigation.

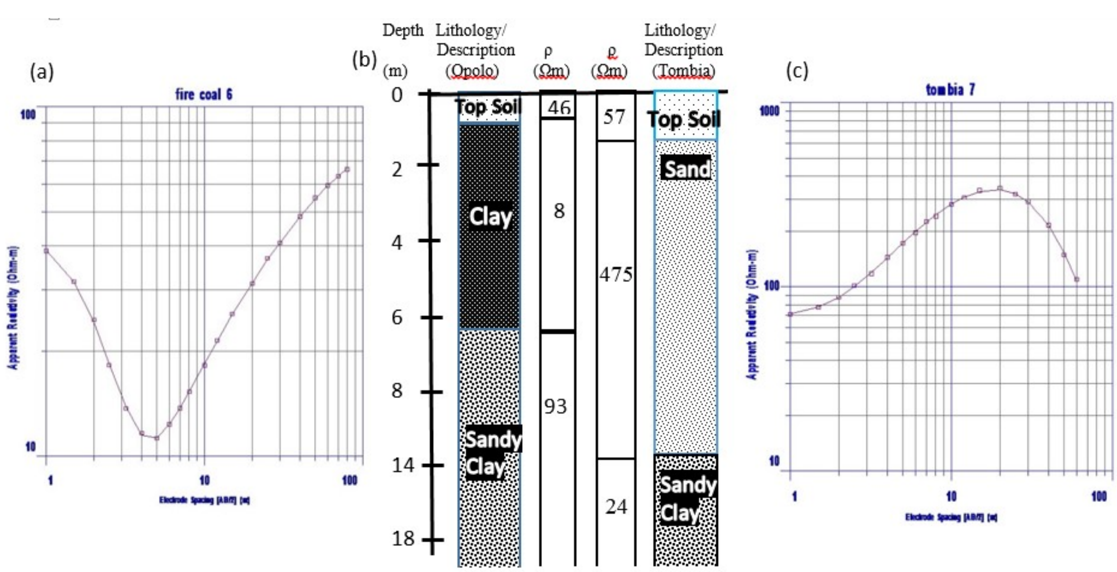


Fig.3: Resistivity model result at Opolo and Tombia (a and c) respectively. (b) Modeled VES lithologicinterpretation.

*Site one interpretation (Opolo)*

The resistivity model results from Opolo shows that the area is predominantly H-curve (Figure. 4a-i) whose geological layers consist of topsoil, clay and sandy clay where the modeled resistivity values of the second layer are lower than those of the upper and lower layers (ρ1>ρ2<ρ3). The resistivity, thickness, and depth of each profile are summarized in Table 1.

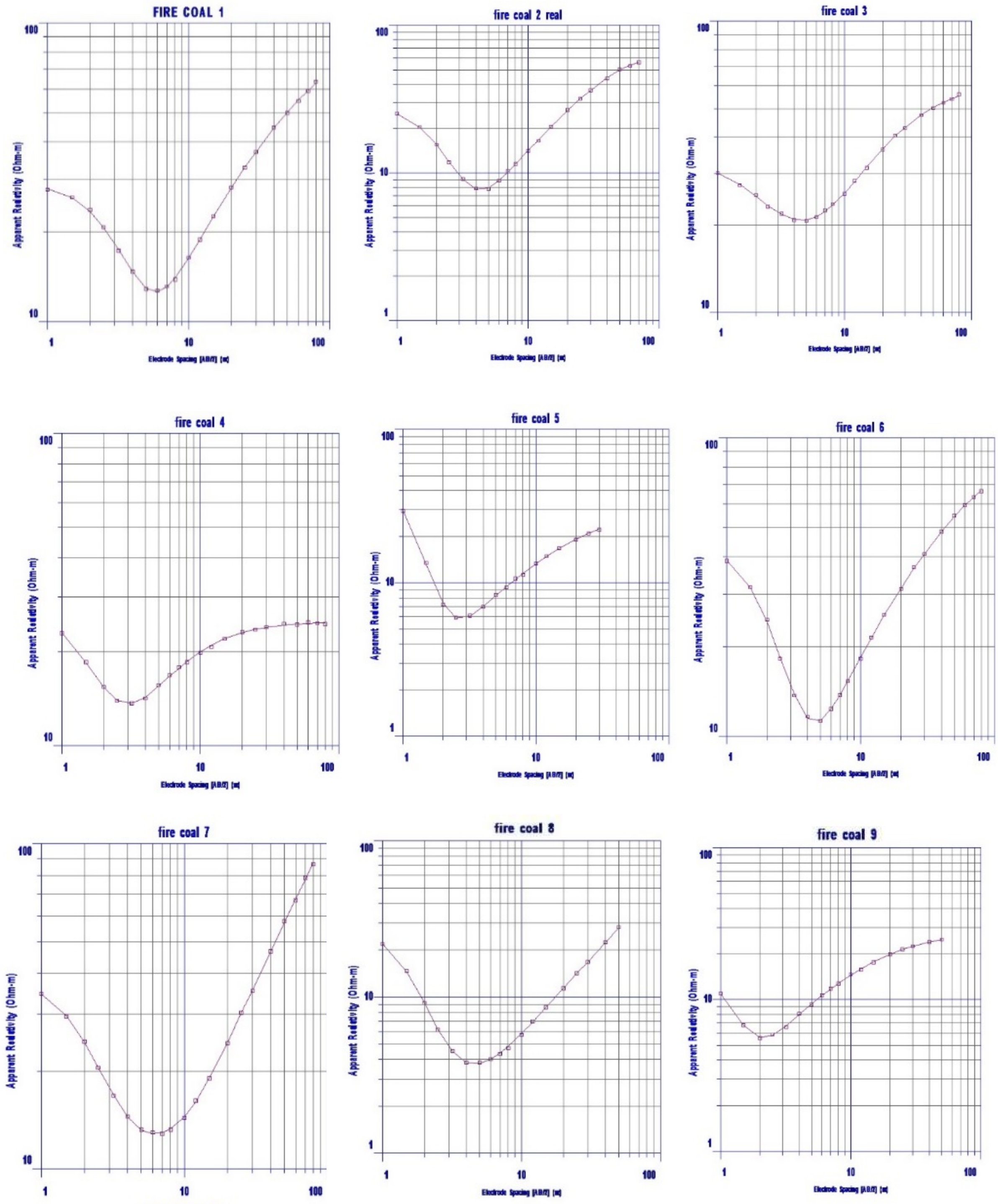


Fig. 4: Resistivity curves of each profile in opolo

The result as summarized in table 1 shows that sandy clay with a mixture of silt makes up the first layer (Top layer), with a resistance range of 24-63m and thickness ranging from 0.4 m - 1.1 m. The second layer is made up of clay with a resistance range of 3-19 Ωm and thickness ranging from 1.2 m – 7.5 m. The third layer is sandy-clay with a resistance ranging from 26-727m.

Table 1: Summary of VES model results and their corresponding thicknesses and depth for Opolo

| | Layer 1 (Top soil) | | | | Layer 2 (clay) | | | | Layer3(Sandy clay) | | | | Layer 4 (Sand) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VES | ρ | h | d | | ρ | h | d | | ρ | h | d | | ρ | h | d | RMS Error |
| *No* | *(Ωm)* | *(m)* | *(m)* | | *(Ωm)* | *(m)* | *(m)* | | *(Ωm)* | *(m)* | *(m)* | | *(Ωm)* | *(m)* | *(m)* | *(%)* |
| **VES 1** | 30 | 1.1 | 1.1 | | 10 | 5.3 | 6.4 | | 113 | - | - | | - | - | - | 1.035 |
| **VES 2** | 30 | 1.0 | 1.0 | | 3 | 2.0 | 3.0 | | 98 | - | - | | - | - | - | 1.348 |
| **VES 3** | 33 | 0.8 | 0.8 | | 19 | 5 | 5.8 | | 62 | - | - | | - | - | - | 1.792 |
| **VES 4** | 32 | 0.6 | 0.6 | | 11 | 2.0 | 2.6 | | 26 | 32.1 | 34.7 | | 22.6 | - | - | 1.783 |
| **VES 5** | 63 | 0.5 | 0.5 | | 4 | 1.7 | 2.2 | | 30 | - | - | | - | - | - | 1.910 |
| **VES 6** | 46 | 1.0 | 1.0 | | 8 | 3.0 | 4.0 | | 93 | - | - | | - | - | - | 1.327 |
| **VES 7** | 39 | 1.0 | 1.0 | | 11 | 7.5 | 8.5 | | 279 | - | - | | - | - | - | 1.232 |
| **VES 8** | 31 | 0.7 | 0.7 | | 3 | 4.4 | 5.1 | | 727 | - | - | | - | - | - | 1.366 |
| **VES 9** | 24 | 0.4 | 0.4 | | 3 | 1.2 | 1.6 | | 27 | - | - | | - | - | - | 1.565 |

Where ρ is bulk resistivity, h is thickness and d is the depth.

In the pseudo-section, the upper horizontal scale represents the name of the sounding point, and the lower horizontal ruler represents the coordinates of the sounding point. The vertical line shows the point of the sounding in *p,m (m)* which is half the distance between the current electrodes AB/2. Interpretation for tomogram is put sideways (Fig. 5). Opolo's tomogram (Fig. 5) also reveals that the area is in three layers within the depth of investigation with the second layer clearly indicating a low resistivity layer. The tomography image clearly identifies boundaries between distinct lithologies.

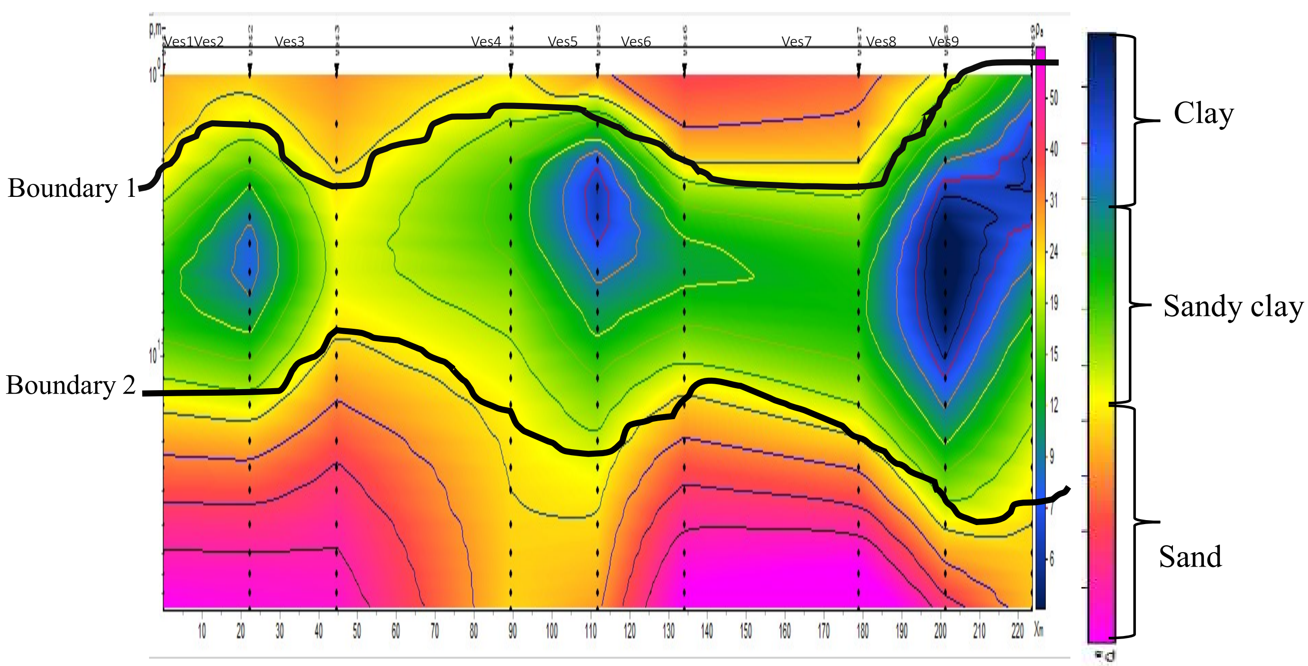


Fig. 5: Opolo's tomogram

*Site two interpretation (Tombia)*

In Tombia, the layers consist of topsoil, sand, and sandy clay and also, the model resistivity of the second layer is higher than those of the upper and lower layers ($\rho 1<\rho 2> \rho 3$). In essence, the "K" resistivity curve type is predominantly obtained in the study area (Fig. 6a-i). Lithology information suggested by the tomogram (Fig. 7) matched well with the obtained result from the model in these locations as it also clearly delineates the three layers. The resistivity, thickness, and depth of each profile are summarized in Tables 1 and 2.

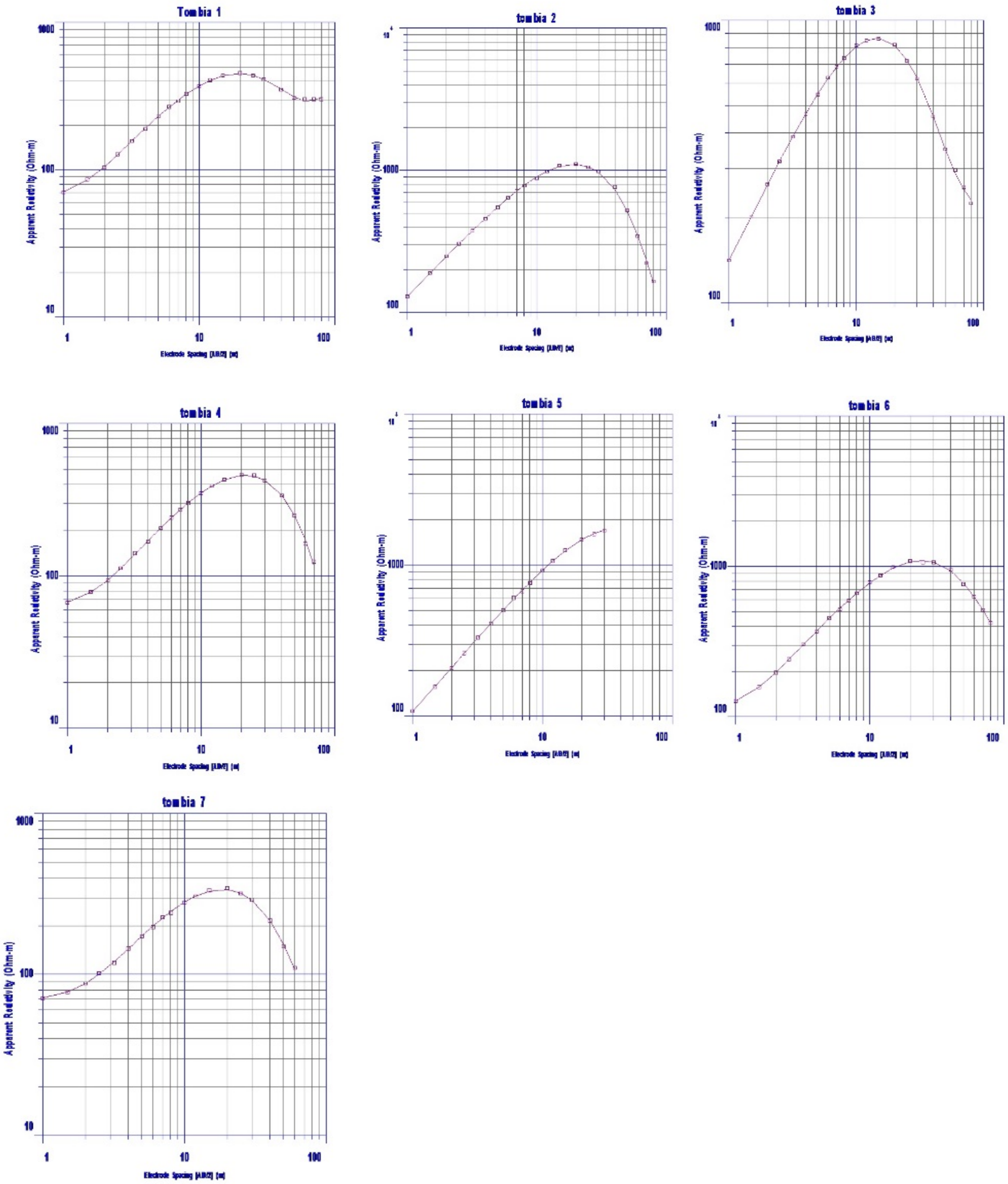


Figure 6: Resistivity curves of each profile in Tombia

The model results as summarized in table 2 show that sandy clay with a mixture of fine sand makes up the first layer (Topsoil) with resistance ranging from 40-1194m. The second layer is made up of Sand with a resistance range of 475-5285m. The third layer is made up of sandy clay/sand with resistance value ranging from 24-28943m. Tobia's tomogram (Figure 7) also reveals that the area is in three layers within the depth of investigation with the second layer indicating a high resistivity layer. The tomography image identifies boundaries between distinct lithologies.

Table 2: Summary of VES model results and their corresponding thicknesses and depth for Tombia

| | Layer 1 (Top soil) | | | | Layer 2 (Sand) | | | | Layer 3 (sandy clay) | | | | Layer 4 (water Saturated Sand) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VES | ρ | h | d | | ρ | h | d | | ρ | h | d | | ρ | h | d | RMS Error |
| *No* | *(Ωm)* | *(m)* | *(m)* | | *(Ωm)* | *(m)* | *(m)* | | *(Ωm)* | *(m)* | *(m)* | | *(Ωm)* | *(m)* | *(m)* | *(%)* |
| VES 1 | 40 | 0.7 | 0.7 | | 809 | 11.7 | 12.4 | | 138 | - | - | | - | - | - | 2.035 |
| VES 2 | 93 | 0.7 | 0.7 | | 1960 | 13.2 | 13.9 | | 33 | - | - | | - | - | - | 1.348 |
| VES 3 | 68 | 0.4 | 0.4 | | 1530 | 8.9 | 9.3 | | 183 | - | - | | - | - | - | 1.552 |
| VES 4 | 55 | 1.2 | 1.2 | | 5285 | 2.2 | 3.4 | | 26 | 4.3 | 7.7 | | 0.014 | - | - | 1.856 |
| VES 5 | 75 | 0.7 | 0.7 | | 5285 | 14.2 | 14.9 | | 65 | - | - | | - | - | - | 1.910 |
| VES 6 | 91 | 0.8 | 0.8 | | 1763 | 18.9 | 19.7 | | 97 | - | - | | - | - | - | 1.327 |
| VES 7 | 57 | 1.1 | 1.1 | | 475 | 15.0 | 16.1 | | 24 | - | - | | - | - | - | 1.232 |
| VES 8 | 1194 | 2.5 | 2.5 | | 492 | 3.5 | 6.0 | | 28943 | 6.0 | 12.0 | | 203 | - | - | 1.366 |
| VES 9 | 91 | 0.8 | 0.8 | | 1763 | 18.9 | 19.7 | | 97 | - | - | | - | - | - | 1.327 |

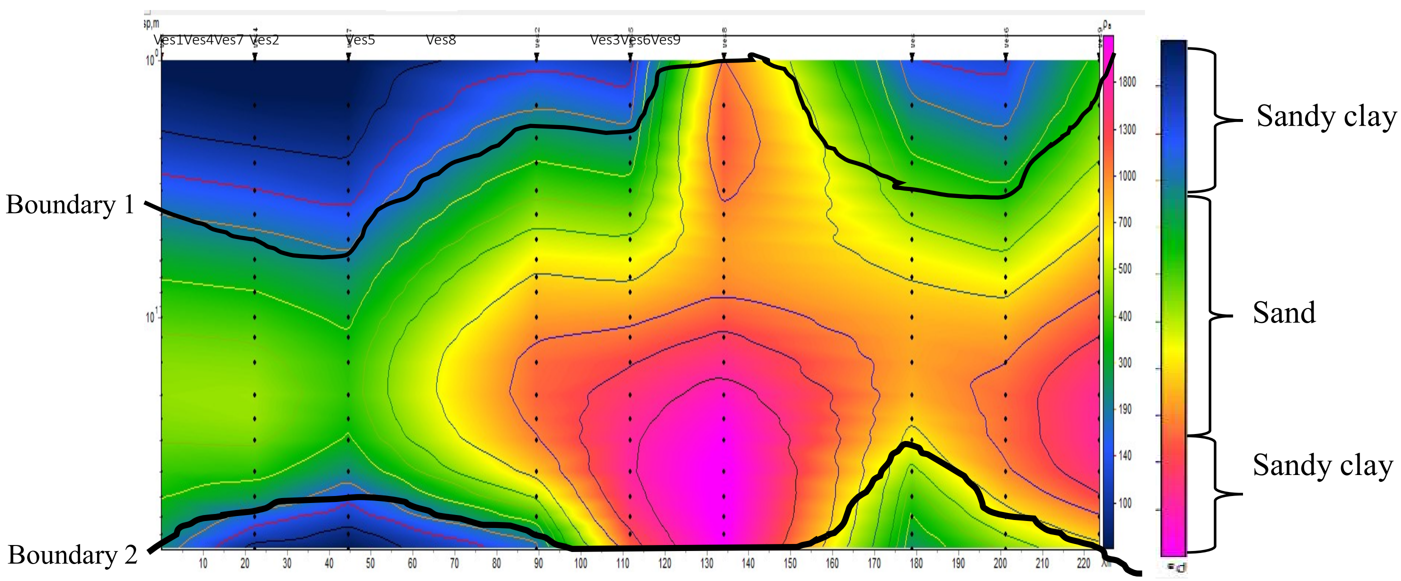


Figure 7: Tombia's tomogram

Where ρ is bulk resistivity, h is thickness and d is the depth.

## V. CONCLUSION

VES technique carried out at eighteen VES stations in two different locations in Yenagoa local government area of Bayelsa State, South-south, Nigeria. The interpreted VES curves in Opolo reveals that the area is of three layers within the depth of investigation. Sandy clay with a mixture of silt makes up the first layer (Top layer) with a resistance range of 24-63Ωm. The second layer is made up of thick clay with very low resistivity values ranging from 3-19Ωm. The third layer is sandy-clay with its resistance value ranging from 26-727Ωm. The interpreted VES curves in Tombia reveals that the area is in three layers within the depth of investigation. Sandy clay with a mixture of fine sand makes up the first layer (Topsoil) with its resistance values ranging from 40-1194Ωm. The second layer is made up of fine sand with resistivity value ranging from 475-5285Ωm. The third layer is made up of sandy clay/sand with its resistance value ranging from 24-28943Ωm. The 1D pseudo section was used to create the tomogram which identified lithology and it's lithological boundaries.

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