

Full Length Research Paper

Geophysical evaluation and chemical analysis of kaolin clay deposit of Lakiri village, southwestern Nigeria

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A geophysical survey using the vertical electrical sounding (VES) technique was carried out to evaluate kaolin clay mineral deposit of Lakiri village, Obafemi-Owode local government area of Ogun State, Southwestern, Nigeria. Thirty three (33) Schlumberger vertical electrical soundings (VES) were acquired at three different sites. The data obtained was interpreted using WingGLink software to determine the apparent resistivity and thickness of each geoelectric layer. A minimum of three geoelectric layers and a maximum of five geoelectric layers were delineated. The subsurface lithology includes: topsoil, clayey sand/sandy clay, kaolin clay and sandstone. The kaolin clay distribution was identified in about 80% of the VES stations with resistivity values ranging between 1099 - 22037 Ω m and thicknesses between 0.4 - 17 m. Chemical analysis carried out on samples collected from these sites shows that the kaolin clay is acidic and contains high concentration of alkaline metals. The physical analyses revealed the kaolin clay to have an average porosity of 0.46 and bulk density of 1.4 g cm⁻³. The study also revealed that the percentage of clay in the samples collected was found to be higher than that of silt and sand.

Key words: Kaolin clay, resistivity, bulk density, electrical sounding and geoelectric layers.

INTRODUCTION

Kaolin (hydrated aluminum silicate, $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$), is an important industrial clay for economic benefit. Properties of fine particle size, platy shape, inertness, non-toxicity, as well as high brightness and whiteness make it a more versatile mineral, with applications in a wide variety of industries. Commercial kaolin resources are found as sedimentary deposits and as weathering or hydrothermal alteration product of rocks containing a high proportion of alumino-silicate minerals. The earth sciences use the clay minerals in the earth crust:

- (i) As indicators of the environment during weathering, allothi- and authi-genesis in the sediments and in the study of source area of the detrital supply;
- (ii) As pH indicators and indicators of processes in micro- and mega-environments and of changes in the course diagenesis and metamorphosis, mineralogical, petrological, geological and geochemical investigations of clay minerals serve as one of the correlation methods, in

the recognition of processes in the petroleum-bearing sediments, coal-bearing formations, origin of riverine, lacustrine, marine, oceanic sediments, climatic, geodynamic, paleogeographical, stratigraphic and weathering rate interpretations (Konta, 1995).

Kaolin belongs to the group of clay minerals that contains atoms of silicon, aluminum, oxygen, ferrous and ferric iron, and hydroxyl groups as the main constituents. It also has other elements such as phosphorus, potassium, calcium, sodium, magnesium, etc. in minutest quantities. Members of the kaolin family include dickite, nacrite, allophone, and hallosite (Brindley, 1951). The iron content in each type of kaolin clay determines its colour. It is usually white to near white in colour. Other colours such as purple, bleach brown, etc., are due to the impurities in the material.

Kaolin deposits are wide spread throughout Nigeria. Almost every state in Nigeria has at least one known deposits of kaolin. In Anambra state, there is the Ozubulu deposit, Darazo deposit in Bauchi, Akpene-Obom deposit in Cross-River state, Kankara deposit in Kaduna state, just to mention a few. The three most extensively studied deposits are the Ozubulu deposits,

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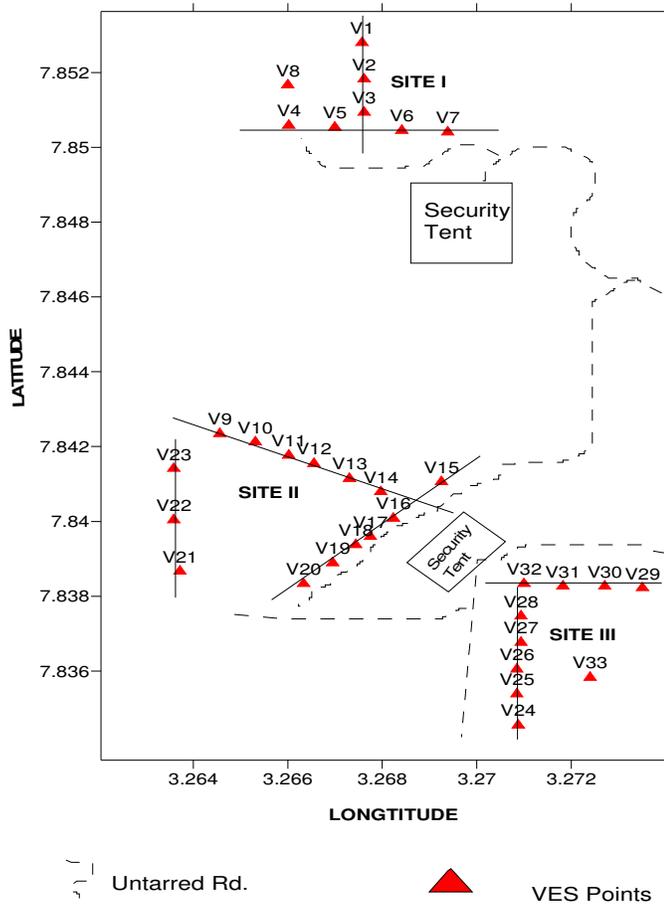


Figure 1. Data acquisition map of the study area.

Kankara deposits and Porter deposits in Plateau state. Odozi and Odeyemi (1996) used a statistical approach, rank-correlation, to show relationships between physical and chemical properties of the Kankara kaolinities.

Several authors have carried out investigations on clay minerals Ajayi and Agagu (1981). The geological setting of the kaolin deposits in lower Cretaceous fluvial Chaswood formation, Nova Scotia, was interpreted from high-resolution seismic-reflection profiles and boreholes, and mineralogical studies on one reference borehole (Hundert et al., 2006). Saviano et al. (2005) used chemical analyses, X-ray diffraction, differential thermal analysis, scanning electron microscopy and isotope analyses to model kaolinite occurrences in Southern Angola.

Prior to 1975, the production of kaolin in Nigeria had been very irregular, insignificant and production data were not properly documented. Only in 1970 did the total production of Kaolin got to as much as 400 tones. In 1975, 560 tones alone were produced. A peak production of 3.4 thousand tones was explored in 1976 as reported by Federal Ministry of Mines, Power and Steel, Mines Department. Nigeria is endowed with extensive kaolin deposits and potential consumer industries abound in the country. Hence, there is need for

intensive prospecting and exploitation of the deposits to meet market demands.

STUDY LOCATION

The study was carried out at Lakiri Village in Obafemi-Owode local government area of Ogun State. It is located within latitude $7^{\circ} 8' N$ and longitude $3^{\circ} 26' E$ in South western part of Nigeria. It has accessible and well connected roads and foot paths (Figure 1). Three different sites were selected and investigated: site A is within latitude $7^{\circ} 8' 31'' N$ and longitude $3^{\circ} 26' 36'' E$; site B is within latitude $7^{\circ} 8' 23'' N$ and longitude $3^{\circ} 26' 38'' E$; site C is within latitude $7^{\circ} 8' 23'' N$ and longitude $3^{\circ} 27' 6'' E$.

Geology of the study area

Lakiri Village falls within the basement complex terrain of Southwestern Nigeria. Though has an appreciable thickness of sedimentary rock formation, it is underlain by crystalline rock of the basement complex, Precambrian to upper Cambrian age (Hockey and Jones, 1964; Oyawoye, 1964). The dominant rock types include a variety of hard to very hard rocks which have metamorphosed in varying degrees to migmatites and gneisses and intruded by granites (Figure 2). Ogun State relief analysis shows that the area comprises of three main physiographic regions which include: the Creek and Lagoon region; Undulating coastal plain; and the desert undulating zone of basement complex region.

METHODOLOGY

Vertical electrical sounding

The electrical properties of the subsurface of the earth were obtained through vertical electrical soundings (VES). According to standard procedure in the Schlumberger configuration, the electrodes were moved in steps further out from a fixed center in order to achieve greater current penetration into the ground. ABEM Terrameter and its accessories were used in acquiring the field data with a maximum current electrode spacing of 160 m. A total of thirty three (33) VES were carried out at three sites within Lakiri village as shown in the data acquisition map (Figure 1). The results obtained were processed using WinGLink, software developed by GEOSYSTEM. This was used to mask individual data points, produced smooth 1D layered inversion model for each VES station (Figure 7), contour maps (Figures 6a and b) and the geoelectric profiles (Figures 3; 4a, b and c; 5a and b).

Physical analysis

Particle size distribution: The rock samples taken from the sites were ground into powder and passed through 2 mm sieve. 50 g of the samples were weighed into different conical flask. 50 ml of 5% sodium hexametaphosphate was added along with 100 ml of distilled water. The mixture was stirred with a stirring rod and left to settle for 30 min. It was later stirred for 15 min with the multimixer

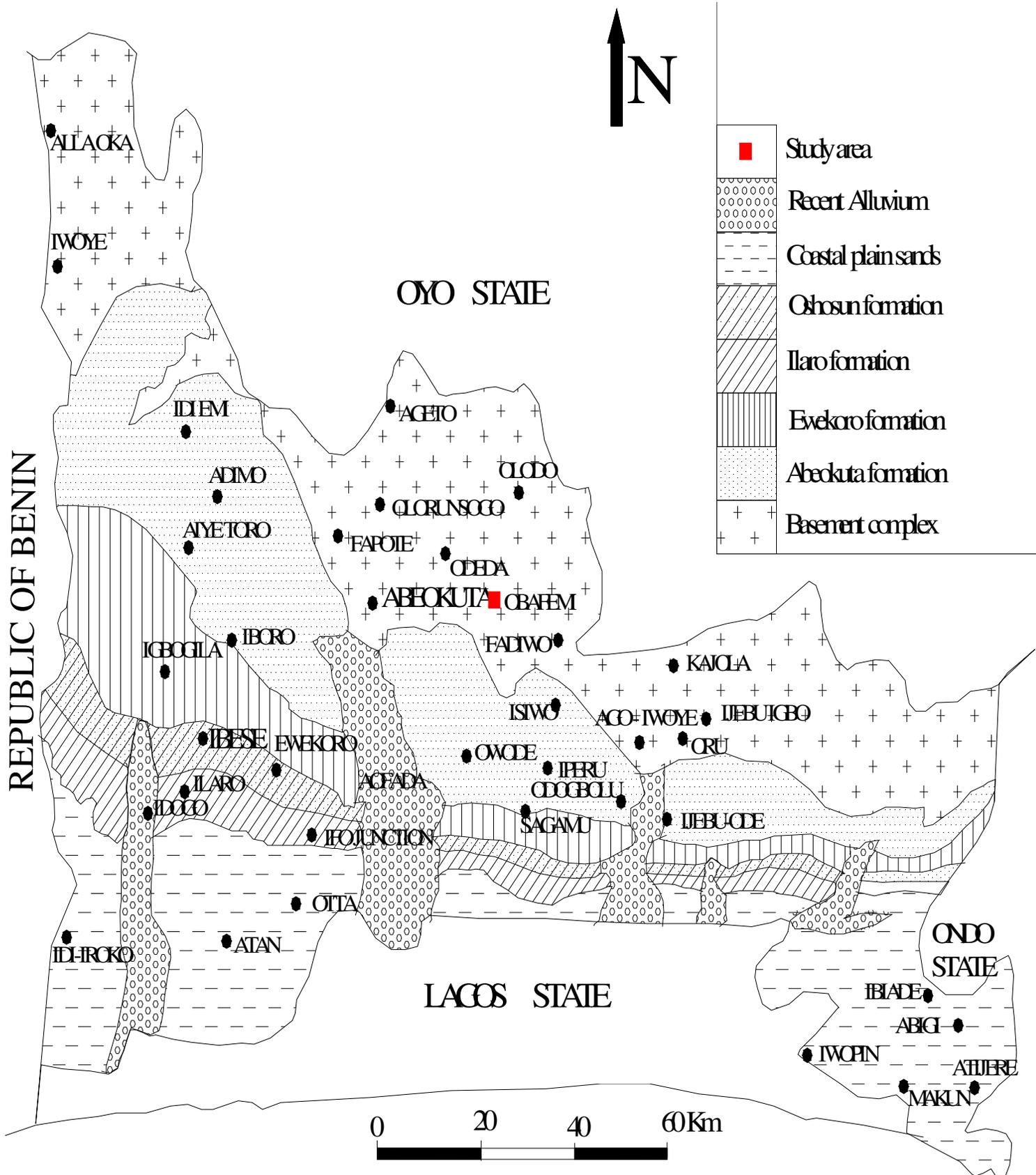


Figure 2. Geological map of Ogun state showing the study area.

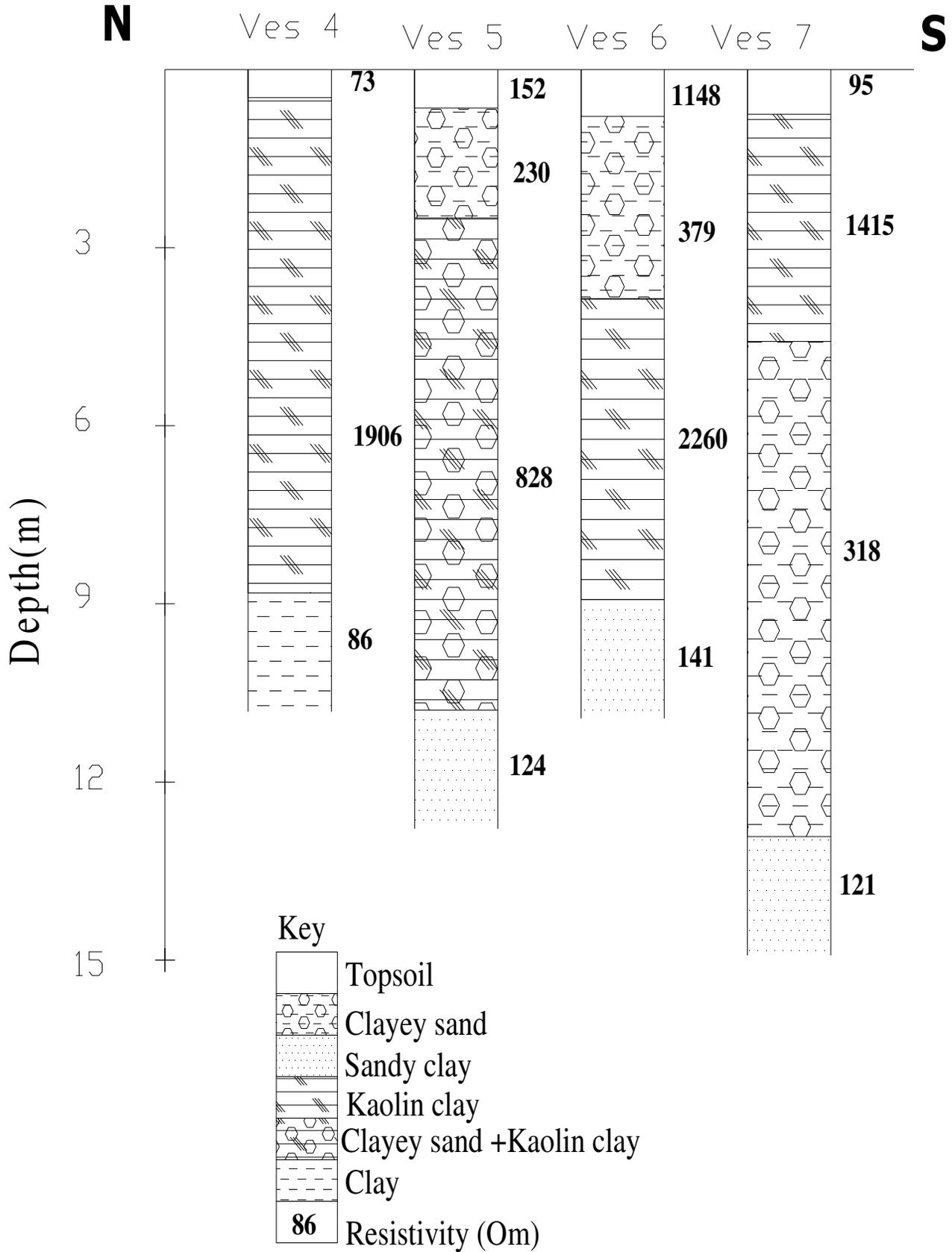


Figure 3. Geoelectric section beneath VES 4 - 7.

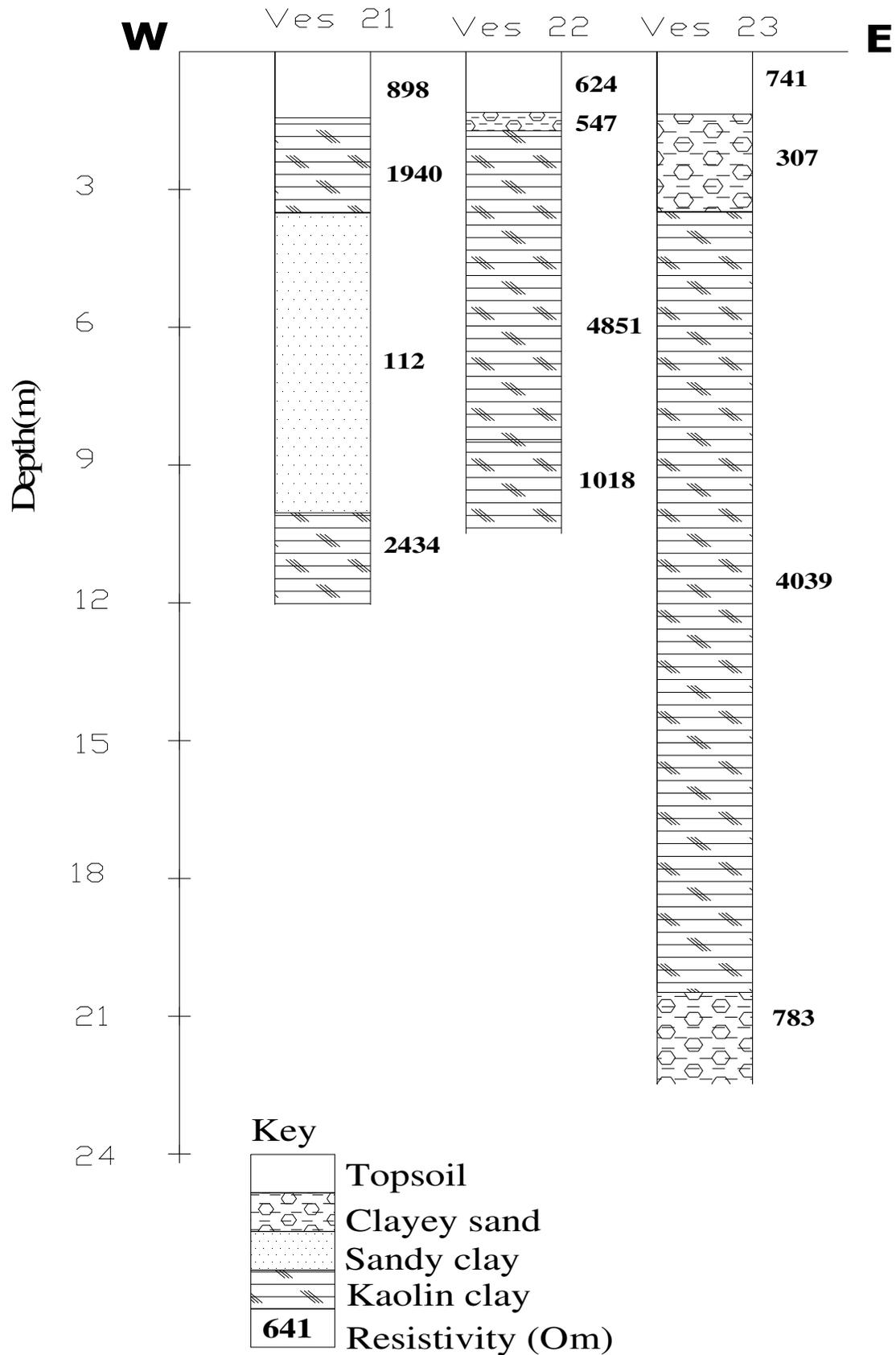


Figure 4a. Geoelectric section beneath VES 21 – 23.

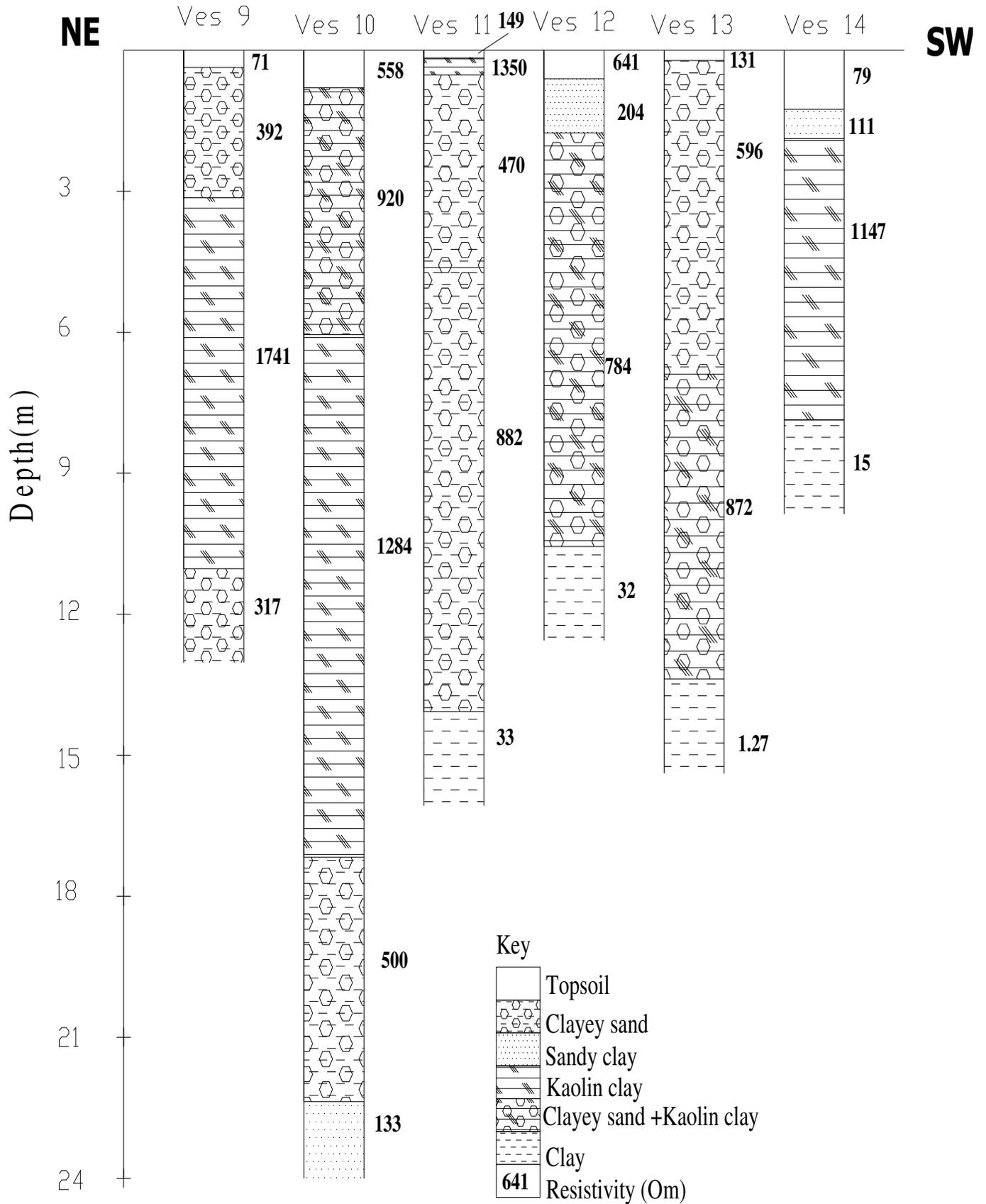


Figure 4b. Geoelectric section beneath VES 9 – 14.

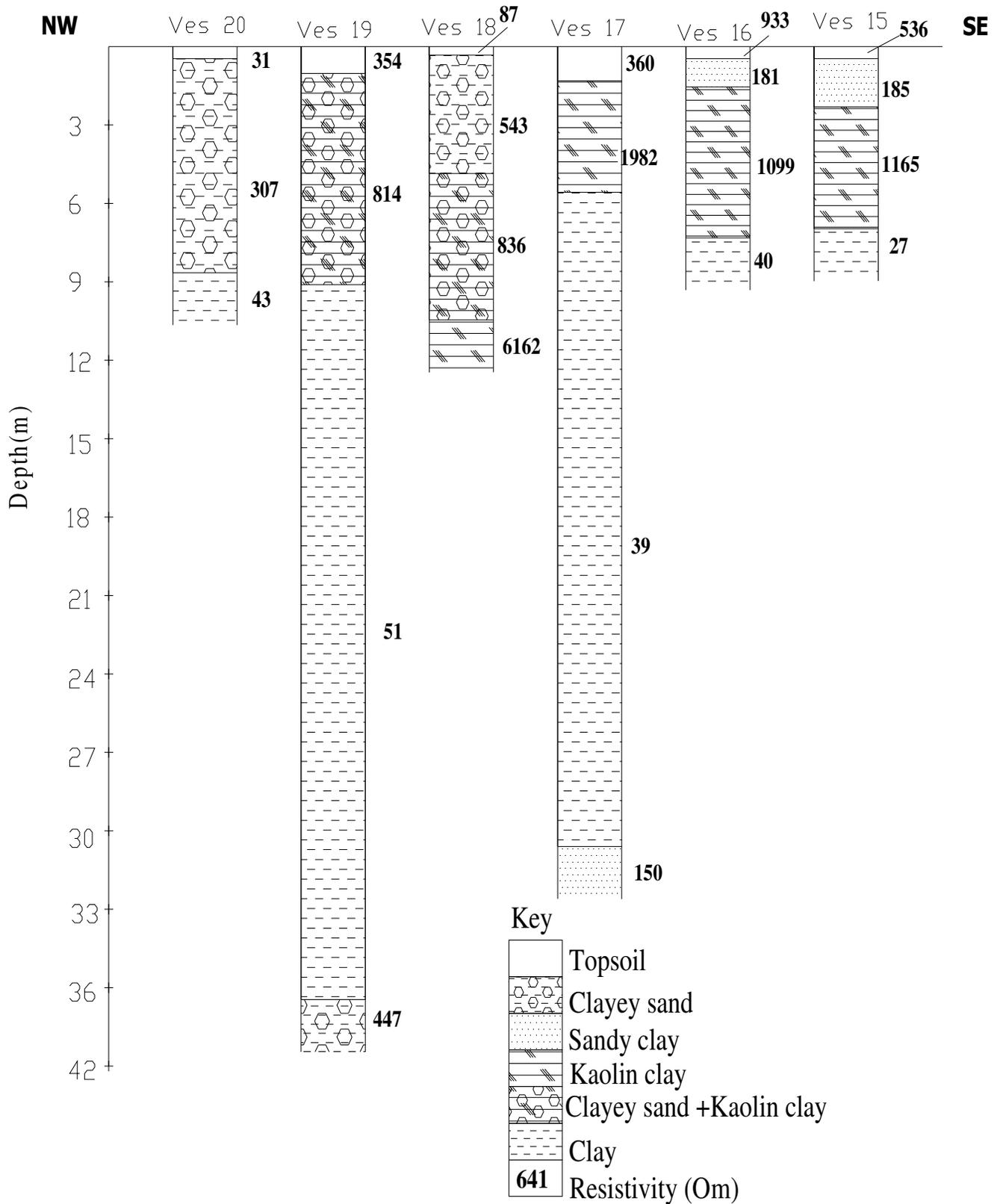


Figure 4c. Geoelectric section beneath VES 20 - 15.

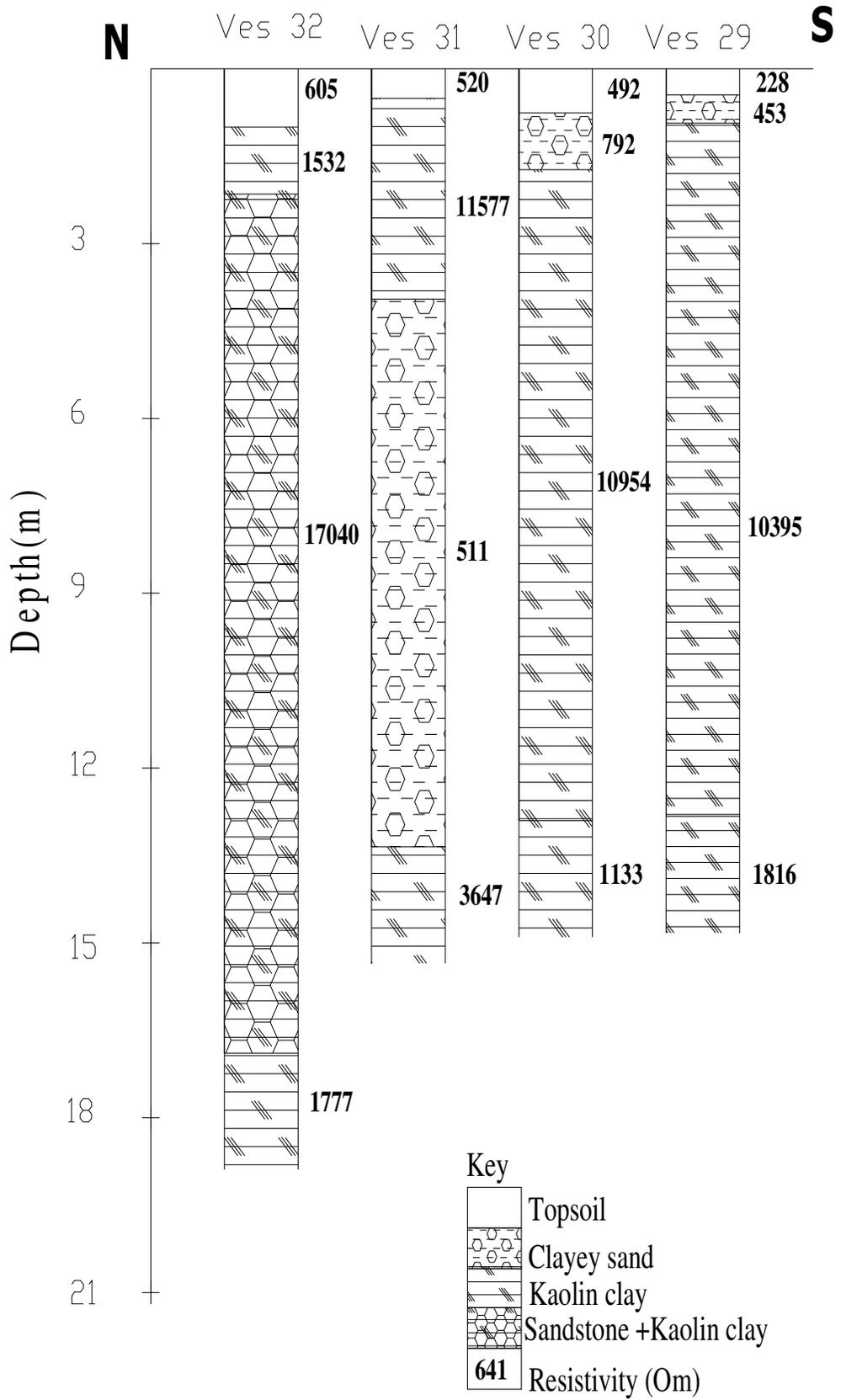


Figure 5a. Geoelectric section beneath VES 32 - 29.

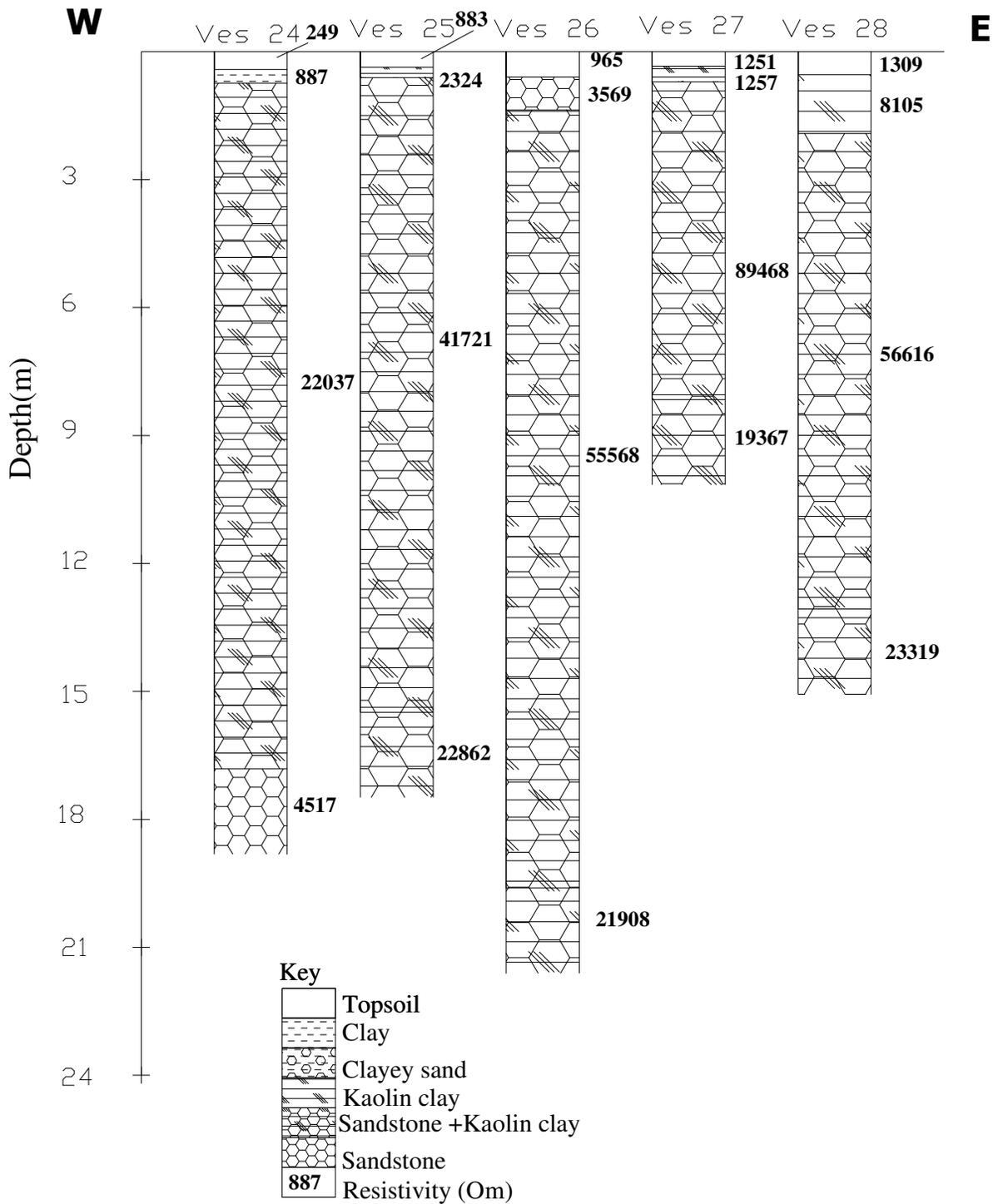
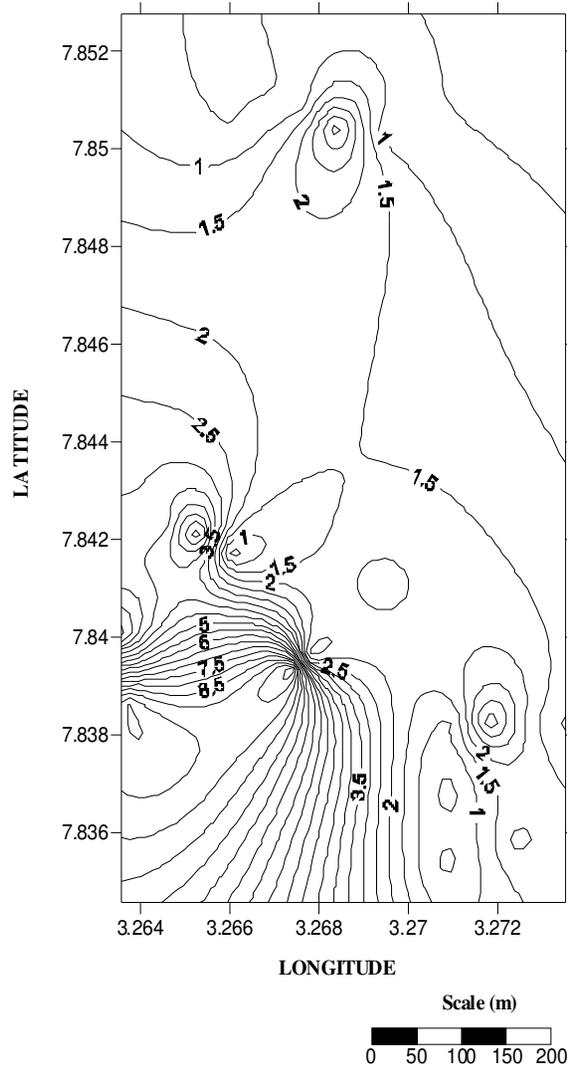


Figure 5b. Geoelectric section beneath VES 24 - 28.

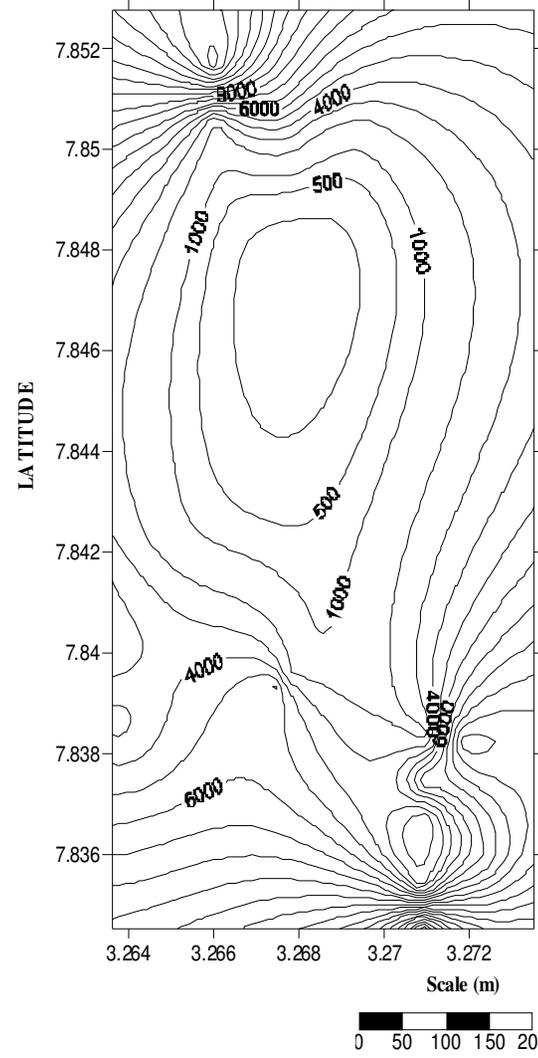
multimixer machine and transferred to the glass cylinder where more distilled water was added to the 1000 ml mark on the cylinder. The top of the cylinder was covered with hand and inverted several times until all the soil was in suspension. The cylinder was

placed on its flat surface and the time was noted.

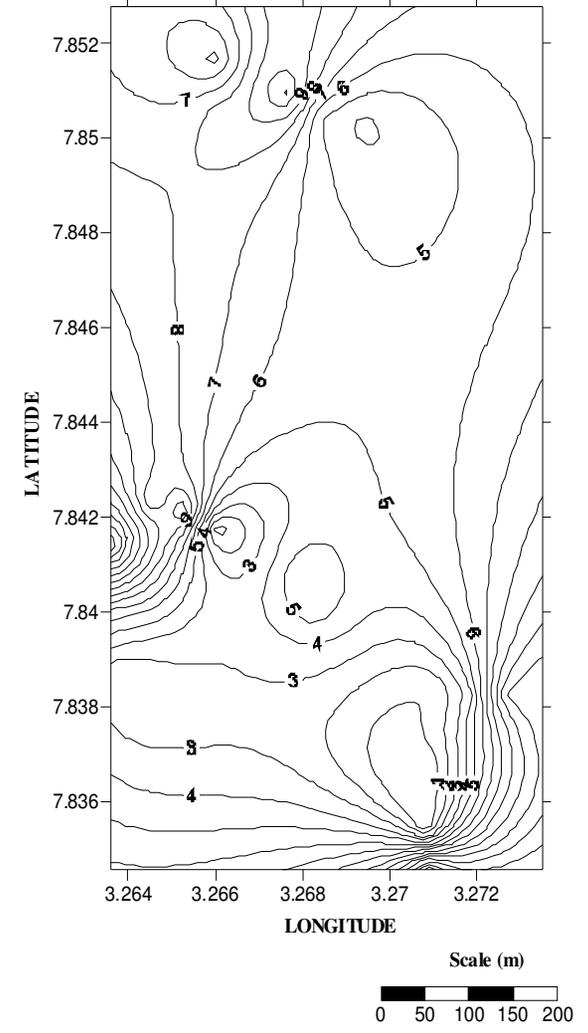
Soil hydrometer was placed immediately into suspension and the first reading on the hydrometer was taken 40 s after the cylinder settled down. The temperature was assumed constant throughout



Contour Map showing overburden thickness (m)

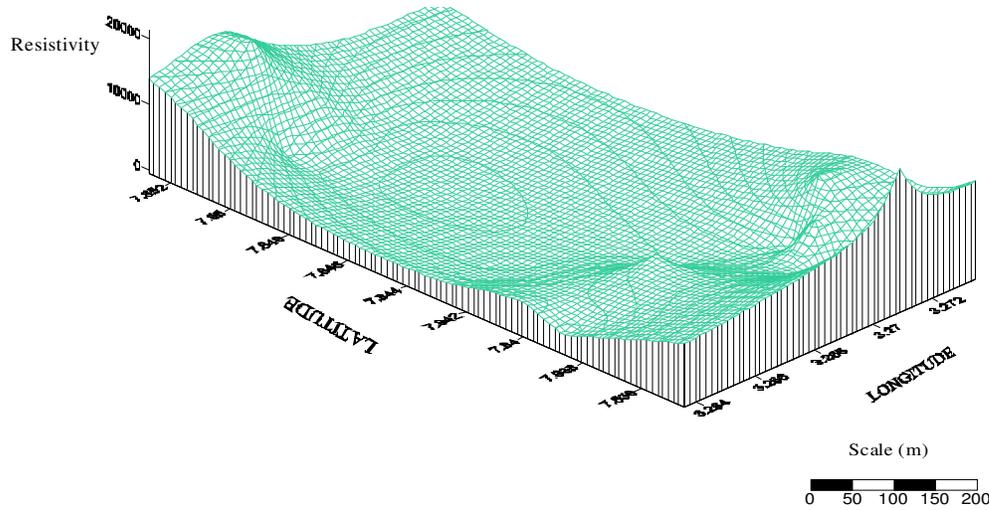


Contour Map showing Kaolin Resistivity(Ohm-m)

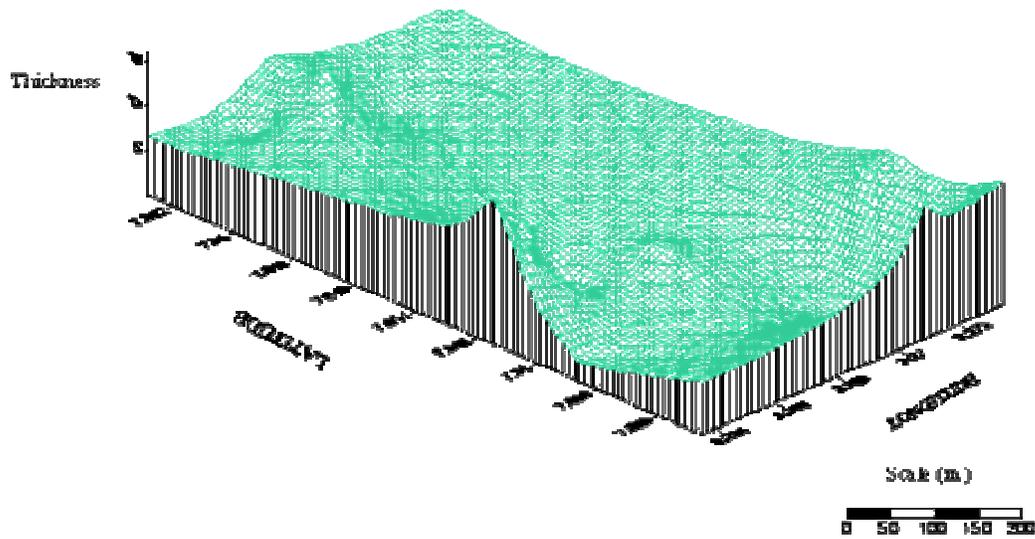


Contour Map showing Kaolin thickness (m)

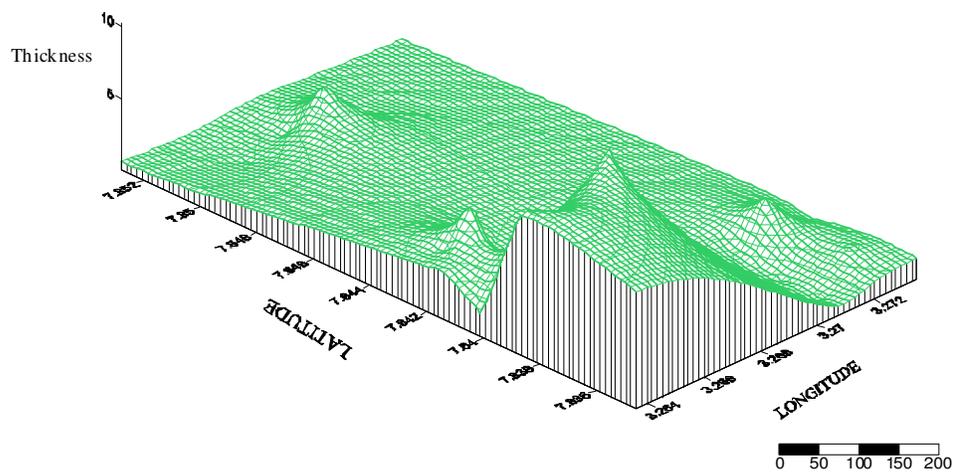
Figure 6a. Contour maps.



3D View Contour Map showing Kaolin Resistivity(Ohm-m)



3D View Contour Map showing Kaolin thickness (m)



3D View Contour Map showing overburden thickness (m)

Figure 6b. 3D View contour maps.

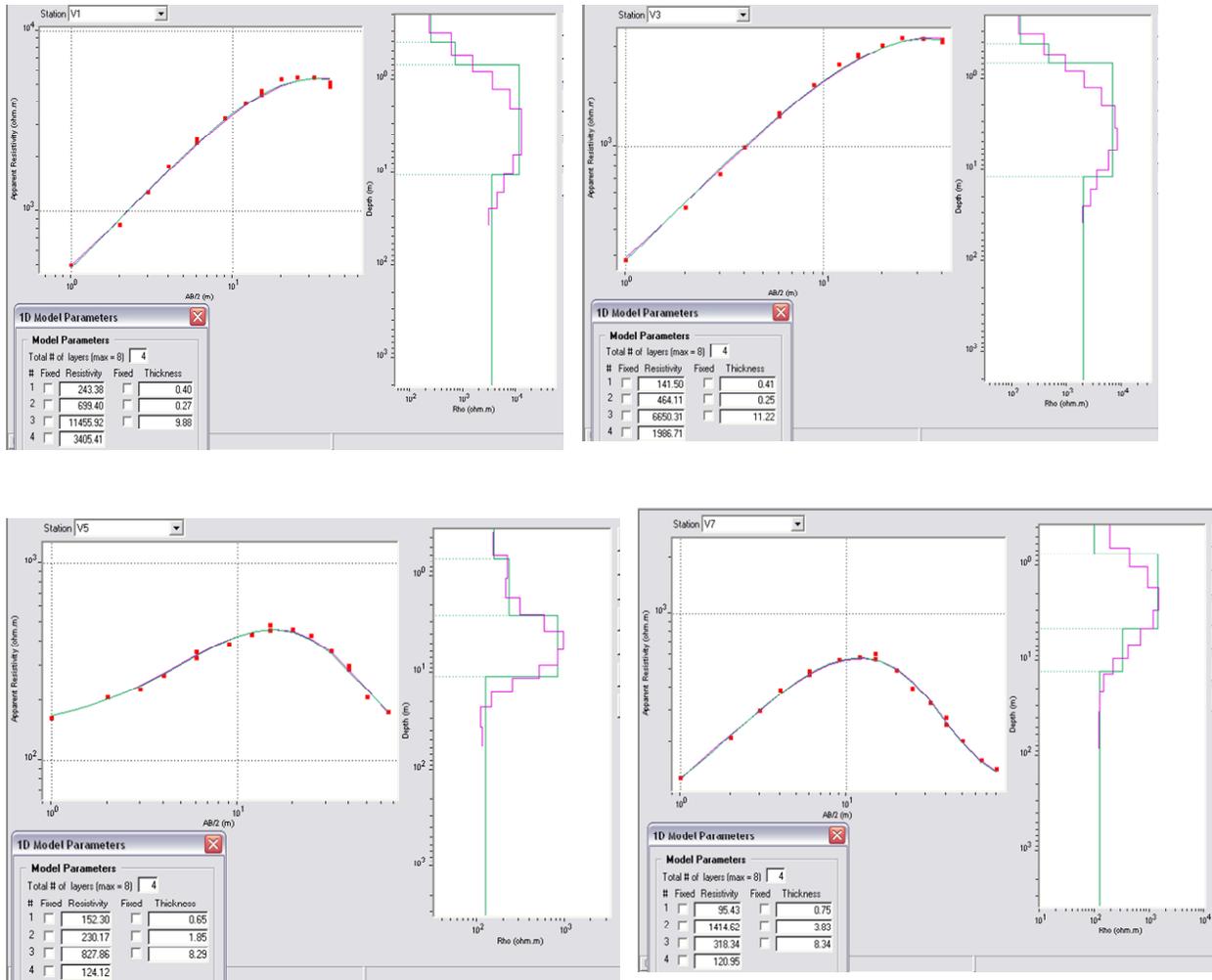


Figure 7. Computer modeling for some selected sounding stations.

Table 1. Hydrometer and temperature measurement.

Samples	Hydrometer readings (H ₁) after 40 s	Hydrometer readings (H ₂) after 3 h
A	39.0	31.0
B	30.0	23.0
C	49.0	40.0
D	38.0	30.0
E	37.0	30.0
F	46.0	32.0
G	21.0	15.0
H	29.0	24.0
I	32.0	23.0
J	30.0	21.0
K	33.0	23.0
L	38.0	29.0
M	39.0	27.0
N	45.0	33.0
O	37.0	28.0

Temperature: T₁ (°F) = 81.5; T₂ (°F) = 82.4.

throughout the first set of hydrometer readings. The second set of readings was taken when the suspension remained for three hours (Table 1).

The particle size contained in a particular sample can be calculated in % using the following relations:

$$\% \text{ sand} = 100 - [H_1 + 0.2(T_1 - 68^\circ\text{F}) - 2]2 \dots\dots(1)$$

$$\% \text{ clay} = [H_2 + 0.2(T_2 - 68^\circ\text{F}) - 2]2 \dots\dots(2)$$

$$\% \text{ silt} = 100 - (\% \text{ sand} + \% \text{ clay}) \dots\dots(3)$$

Determination of bulk density: The samplers were taken directly from the field using the sampler, and both ends of the cylindrical shaped hallowed metal were covered to prevent evaporation. The samplers were placed in the oven for 24 h at 105°C and later weighed to give mass of sample plus mass of sampler (m_1) in grammes. The sampler was emptied and weighed to give mass of empty sampler (m_2) in grammes. The mass of oven-dried sampler was obtained as: $m_3 = (m_1 - m_2)$

The diameter of the cylindrical sampler was measured and the bulk density was calculated as follows:

$$\text{Bulk density}(\rho_B) = \frac{\text{mass of oven - dried sample}}{\text{volume of sampler}}$$

$$= \frac{m_3(g)}{\pi r^2(cm^2)}$$

Determination of porosity: The pores of a rock sample can be deduced from the relationship between bulk density and the density standard for tropical soil given as;

$$\text{Porosity} = 1 - \frac{\text{Bulk density}}{\text{Tropical soil density}}$$

$$= 1 - \frac{\rho_B}{\rho_S}$$

Where ρ_B is the bulk density, ρ_S is the density for tropical soil with value 2.65 gcm⁻³.

Measurement of electrical conductivity: 10 g of the sample was weighed into the sample and 50 ml of distilled water was added. This was placed on a mechanical shaker and shook for one hour. The solution was decanted into a beaker where the measurement was done. The results are shown in the tables given. The electrical resistivities of the samples were calculated using conductivity-resistivity relation.

$$\text{Conductivity } \sigma = \frac{1}{\text{Resistivity } \rho}$$

Chemical analysis

Measurement of pH: 2 g of the sample (passed through 2 mm sieve) was weighed into a sample bottle and 20 ml of distilled water was added. The samples were placed on a mechanical shaker and were shaken for three hours and allowed to settle for 30 min. The electrode of the pH meter was inserted into the partially settled suspension and the pH value of the samples was measured.

Determination of organic carbon content: This was determined using Walkley and Black method. A representative sample

grounded to passes through 0 – 5 mm sieve. 1 g of the sample was used by pipeting 10 ml of K₂Cr₂O₇ solution to the sample in the flask. 20 ml of concentrated H₂SO₄ was added immediately, mixed and shaken vigorously and allowed to remain for 30 min until it cool. Another 100 ml of distilled water was added later 4 drops of ferroin indicator was added and filtration was done with ferrous ammonium sulphate solution until the colour changed to maroon.

The percent organic carbon is obtained as;

$$\% \text{ organic carbon} = (B - S) \times 0.4N \times 0.003 \times 100 \times f \text{ mass of air-dried sample}$$

Where;

B is a constant called the blank = 28.1

S is the titration value

N is the normality of the solution

f is the correction factor = 1.33.

Therefore, % organic matter of the sample = % organic carbon × 1.729.

Total nitrogen content: This was carried out using the regular Macro-Kjeldahl method. 5 g of the sample round to pass through 0.5mm sieve was weighed into the 500 ml Macro-Kjeldahl flask. 20 ml of distilled water was added and the flask was swirled for a few minutes and then allowed to settle for 30 min. A tablet of Selenium catalyst and 10 g of K₂SO₄ were added, followed by 30 ml of concentrated H₂SO₄ through automatic pipette. The flask was gently heated at low temperature.

Phosphorus content: This was determined by Bray-1 method (Bray and Kortz, 1945). 1 g of air-dried sample passed through a 2 mm sieve was weighed and mixed with extracting solution (15 ml of NH₄F and 25 ml of HCl to 460 ml of distilled water). Vigorous shaking was done manually for 15 min in a centrifuge. 2 ml of clearer supernatant was pipette into a 20 ml test-tube. 5 ml of distilled water and 2 ml of ammonium molydate solution [(NH₄)₆MO₇O₂₄.4H₂O] and 1 ml of stannous chloride (SnCl₂.2H₂O) were added.

After 5 min, absorbance was measured on the electro-spectrometer at 660 nm. Content of the extractable phosphorus in the samples were calculated from the graph of an equation passing through the origin.

$$y = mx, \quad m = \frac{y}{x}$$

$$\text{Average } m = \sum \frac{m_i}{5} \quad i = 1 \text{ to } 5$$

$$\text{Available phosphorus} = \text{Average } m \cdot E$$

Where E is the electro-spectrometer reading.

Exchangeable acidity: 5 g of the sample passed through 2 mm sieve was weighed into a 45 ml centrifuge tube and 30 ml of KCl was added. The content was centrifuged at 2 rpm for 15 min. The clear supernatant was decanted into a 100 ml volumetric flask. Another 30 ml of KCl was added to the sample and shaken for 30 min and decanted as before 25 ml of KCl extracted was pipette into a 250 ml Erlenmeyer flask. Approximately 100 ml of distilled water was added as well as 5 drops of Phenolphthalein indicator. Titration was done with NaOH to a permanent pink end point.

Table 2. Summary of VES interpretation.

VES station	Kaolin resistivity (Ω m)	Kaolin thickness (m)	Overburden thickness (m)
SITE I			
1	11455.92	0.67	10.55
2	-	-	-
3	6650.31	0.66	11.88
4	1906.16	0.47	8.82
5	-	-	-
6	2260.10	3.86	8.93
7	1414.62	4.58	4.58
8	17518.07	0.42	5.06
SITE II			
9	1740.46	3.14	11.03
10	1283.62	11.12	6.05
11	1349.55	0.37	0.16
12	-	-	-
13	-	-	-
14	1146.80	5.99	1.88
15	1164.91	4.65	2.31
16	1098.57	5.78	1.54
17	1982.08	4.26	1.31
18	6161.99	-	10.45
19	-	-	-
20	-	-	-
21	2433.91	-	10.04
22	4851.14	6.78	1.72
23	4039.22	17.00	3.48
SITE III			
24	22037.08	16.08	0.74
25	2323.69	0.24	0.37
26	-	-	-
27	1256.47	0.37	0.34
28	8105.44	1.38	0.54
29	10394.54	11.90	0.93
30	10954.42	11.17	1.73
31	11576.58	3.44	0.51
32	1531.74	1.15	1.00
33	7491.70	8.54	2.14

Exchangeable basicity: 100 ml of acetate acid was diluted with 150 ml of concentrated ammonium hydroxide using 2 L of distilled water. 5 g of the air-dried sample passed through 2 mm sieve was weighed into sample bottles and 50 ml of ammonium acetate was added. The mixture was shaken for 30 min.

RESULTS AND DISCUSSION

The geophysical survey carried out at Lakiri village

revealed the occurrence of three to five geoelectric layers at sites I and II while site III is mainly a four-layer model.

The subsurface lithology includes: topsoil, sandy clay (kaolin mixed with shale/clay), kaolin clay, and clayey sand. Kaolin clay deposit exists at the three sites studied. The direct or laboratory measurement of the resistivity of kaolin clay samples collected from these sites using conductivity meter revealed a good correlation with the field measurement as shown in Table 2.

Geoelectric sections

The geoelectric section of site I revealed four layers at VES 1-3 and 5-7 and three layers at VES 4 and 8. Kaolin clay occurs in the second geoelectric layer at VES 4, 7, and 8 while it occurs in the third layer at VES 1, 2, 3, 5, and 6 with resistivity values ranging between 1415 and 17518 Ω m and thicknesses between 3.8 and 11.2 m (Figure 3).

The geoelectric section of site II revealed three geoelectric layers at VES 20, four geoelectric layers at VES 9, 12 - 19, 21, 22, and 23 while at VES 10 and 11, there are five geoelectric layers. Kaolin clay occurs in the second geoelectric layer at VES 11, 17, and 21; however, kaolin clay was revealed at third geoelectric layer in VES 9, 10, 14, 15, 16, and 23 and in the fourth layer at VES 18 and 22. The resistivity values fall within 1099 and 4851 Ω m and thicknesses lie within 0.4 and 17.0 m (Figures 4a, b and c).

The Geoelectric section of site III revealed four geoelectric layers all through. Kaolin clay occurs in the second geoelectric layer at VES 25, 27, 28, 31, 32, and 33 and in the third geoelectric layer at VES 24, 29, and 30.

The resistivity values range is from 1227 to 22037 Ω m and thicknesses from 0.4 to 16.1 m (Figures 5a and b).

Contour maps with 3-D View

Contouring is another technique that was used for interpretation of resistivity data. Kaolin clay distribution of Lakiri village area was contoured using "Suffer software" and three types of contour maps were prepared for this research work (Figures 6). The kaolin clay overburden thickness (Figure 6a) depicts clearly the depth to the kaolin in all the sections. The contour map shows the area of thick overburden/depression, indicated by dense contour closures.

The limestone thickness map (Figure 6b) depicted various thicknesses of all sites sounded and revealed capacity of the kaolin clay deposit within the area. Region of possible fractures/deep-seated faults are depicted by widely spaced closed contour lines, showing the vertical lateral distribution of the kaolin. The resistivity contour map (Figure 6c) however, depicted the spatial distribution of resistivity across the study area.

Other analyses

The physical analysis (the dispersion of the kaolin clay into different particle sizes) revealed the highest percentage of clay (63%) at site I, followed by site III

(58%) and site II (48%) as revealed in Table 3. Site II has the highest percentage of sand (35%) followed by site III (22%) and site I (21%). Also, site III has the highest percentage of silt (20%), followed by site II (17%) and site I (15%). In general, kaolin clay contained showed that site I is extremely acidic with pH value of 4.4. Site II and III are strongly acidic with pH values 4.54 and 4.50 respectively. The percentage organic matter content of this clay mineral is very low, in the range 0.05 - 0.17%. The total nitrogen and the available phosphorus of the rock sample are very low.

Conclusion

The geoelectric investigation of three different sites in Lakiri village, southwestern Nigeria using the Schlumberger configuration of electrical method of geophysical prospecting has revealed the occurrence of vast deposit of kaolin clay mineral which can serve as raw material for industries which produces building materials such as tiles, cement, bricks, plumbing fixtures (sanitary ware) etc and for the production of porcelain ware such as cups and dishes.

This research work further revealed the quality of the kaolin clay both chemical and physical properties as additive for both industrial and mining purposes. However, the presence of this solid mineral has adverse effect on the groundwater potentials of this area, as most aquifers in these sites are overlain by very thick overburden material of fresh deposit of clay/shale and kaolin clay.

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