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RESOURCE QUANTIFICATION OF A KAOLIN DEPOSIT USING THE ELECTRICAL RESISTIVITY METHOD – CASE STUDY FROM IKERE EKITI, SOUTHWEST NIGERIA

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Abstract

The vertical electrical sounding (VES) involving Schlumberger electrode configuration has been used to investigate a kaolin deposit at Ikere in Ekiti State of Nigeria. The survey which covered an areal extent of 20, 000 square meters, involved a sum total of 15 VES stations.

Four geoelectric layers were delineated from the survey area. The first layer is the topsoil whose thickness varies from 0.7 m to 1.5 m and resistivity values range from 150 to 1150 ohm-m. The second layer is lateritic clay with thicknesses ranging from 4.0 to 17.5 m and resistivity values of between 217 and 1460 ohm-m

The third layer which is the kaolin has thicknesses ranging from 19 m to 99.5 m and resistivity values range from 105 to 485 ohm-m. The fourth layer is the basement bedrock. The resistivity values of the bedrock range from 4370 ohm-m to infinity. The investigated area was divided into eight square blocks. The sum of the product of the average thicknesses of the kaolin deposit per block and the surface area of each block was multiplied by an average density, 2.45 gcm^{-3} of the kaolin to determine the reserve of the deposit which was estimated at 2,732,305 tonnes. The volume of the excavable overburden was estimated at 219,818.9 cubic meters. The kaolin deposit can be open mined.

Keywords: Kaolin deposit, resistivity, reserve quantification.

1. Introduction

Electrical resistivity methods involve measurement of apparent resistivity of subsurface materials as a function of depth or position. The resistivity measured is a complex function of porosity, permeability, ionic content of the pore fluids, and clay mineralization. Hence different rocks will exhibit marked differences in resistivities. In varieties of rocks, variation in electrical resistivity will be accompanied by a discernable variation in lithology and chemical composition. Useful information on the structural disposition of bedrock and nature of subsurface can be obtained from surface distribution in resistivity, thus making electrical resistivity applicable to a number of areas of interest.

The electrical resistivity method is commonly used in engineering site investigation. It is relevant in depth to bedrock determination, structural mapping, determination of nature of superficial deposits etc (e.g., Early and Dyer, 1964; Bisdorf, 1985; Olorunfemi and Mesida, 1987; Lucius and Bisdorf, 1995; Bisdorf, 1996). It has become one of the most useful tools in investigations for groundwater e.g., Odufisan (1991) and Olorunfemi and Fasuyi (1993). The method can provide useful and relatively low-cost information on the extent and thickness of fresh-water lenses. Traditionally, vertical electric sounding (VES) has been used for this purpose (Fretwell and Stewart, 1981; Ayers and Vacher, 1986; Kauahikaua, 1986). The electrical resistivity method has proved successful in the mapping of salt water interfaces in many different hydrogeologic settings (Swart and Stewart, 1981; Olorunfemi 1985; Fretwell and Stewart, 1981; Zohdy *et al*., 1993). The resistivity method is also used for mineral investigations e.g., Adepelumi and Olorunfemi (2000), Olowolafe (1991) used vertical electrical sounding (VES) to survey a kaolin deposit at the Ubuluku area of Delta State.

In this study, an electrical resistivity survey involving vertical electrical sounding (VES) technique was carried out for the determination of the reserve of a kaolin deposit at Ikere in Ekiti State (Figure 1). It also aimed at the estimation of the excavable volume of the overburden over the deposit.

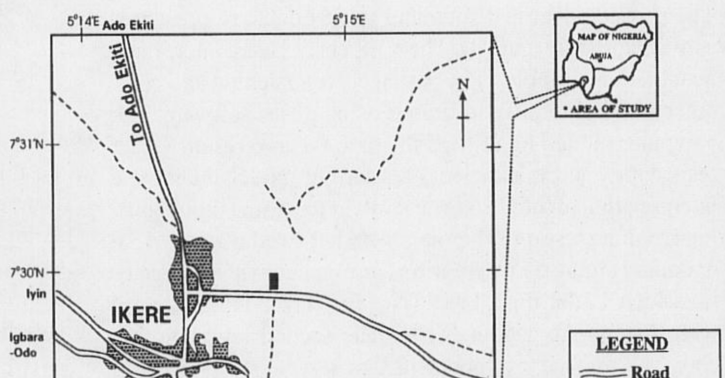

FIGURE 1. LOCATION MAP, SHOWING THE STUDY AREA
(EXTRACTED FROM FEDERAL SURVEY MAP,NIGERIA,1967)

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Kaolin is a clay composed essentially of the mineral kaolinite. It is characterized by its white colour that may be changed according to the level of impurities present. Its melting point is 1785 °C and about 5 to 50 microns in particle size. It is formed as a result of the decomposition of the alumina - silicate minerals, especially the feldspars and hydrothermal alteration (Singh and Gilkes, 1991).

Kaolin is mostly used for chinaware, stoneware and refractories. It is also used in making various types of pottery, fillers in the manufacturing of paper, insecticides and pharmaceutical products. It also finds usage in paint making industry.

2. Geology of the area

Ikere-Ekiti is underlain by rocks of the basement complex of Nigeria. The Nigerian basement complex consist of six major groups or petrological units (Rahaman, 1988). The area investigated is underlain by rocks of the Older Granites suite and Charnockitic rocks. These two groups of rocks form the prominent topographic features within the area. The charnockitic rocks contain quartz, plagioclase, orthopyroxene, ± alkali feldspar ± fayalite ± clinopyroxene ± biotite ± hornblende (Rahaman, 1988). The Older Granite suite on the other hand consists of quartz, alkali feldspar, plagioclase, hornblende, biotite ± zircon, ±sphene, ± apatite (Rahaman, 1988). The parent rock of the investigated deposit, based on information from the geology of the area is coarse-grained charnockitic rock (Figure 2).

3. Methodology

In an attempt to determine the reserve of the kaolin deposit, as well as volume of excavable overburden, the vertical electrical sounding (VES) involving the Schlumberger array was used. The electrode spacing (AB/2) was varied from 1 – 100 m. A total of 15 sounding stations were occupied. The VES stations are shown in Figure 3.

A test pit was also dug in the premises of the survey area (Figure 3) to provide information on the subsurface sequence.

The vertical electrical sounding (VES) data are presented as VES curves (Figure 4). The VES curves were interpreted quantitatively (Table 1) by partial curve matching and computer assisted iterative technique using Resist software. The computer modelling utilised the partial curve results (layer resistivities and thicknesses) as starting models. Geologic interpretation of the VES results was aided by the lithological log from the test pit. The pit penetrated two layers at 15.0 m depth (Figure 5) where it was terminated within the kaolin which is the third layer. The first layer is the topsoil with thickness of about 1.2 m. The second layer lateritic clay with thickness of about 12.0 m.

The interpretation results (layer resistivities and thicknesses) are presented as geoelectric sections (Figures 6 – 8) and isopach maps (Figures 9 and 10).

The survey area was divided into square blocks (Figure 11) and average kaolin thickness per block determined from the isopach map. The volume of the kaolin deposit per block was calculated from square block surface area and the average thickness within each block. The summation of the volumes of the eight blocks gave the total volume of the kaolin deposit. The density of the kaolin was determined using simple displacement method. A standard density bottle was weighed and its weight noted. It was then filled with distilled water, covered and weighed. This weight was recorded as W_w. The water was discarded and 50g of air-dried sample was added to the bottle and filled with distilled water. The whole mixture was shaken together and filled with distilled water regularly to make sure that the bottle was filled to the brim. The weight was recorded as W_T. The procedure was repeated for each of the samples and density was computed from Equation 1.

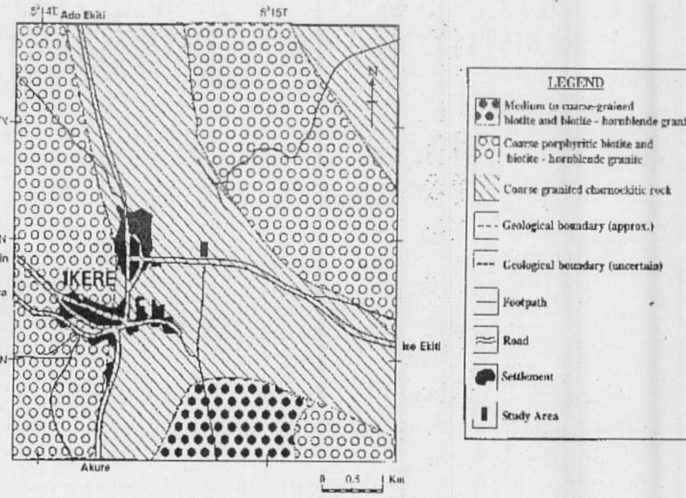

FIGURE 2. GEOLOGICAL MAP OF IKERE -EKITI AREA OF EKITI STATE (Modified, After Olarewaju 1987)

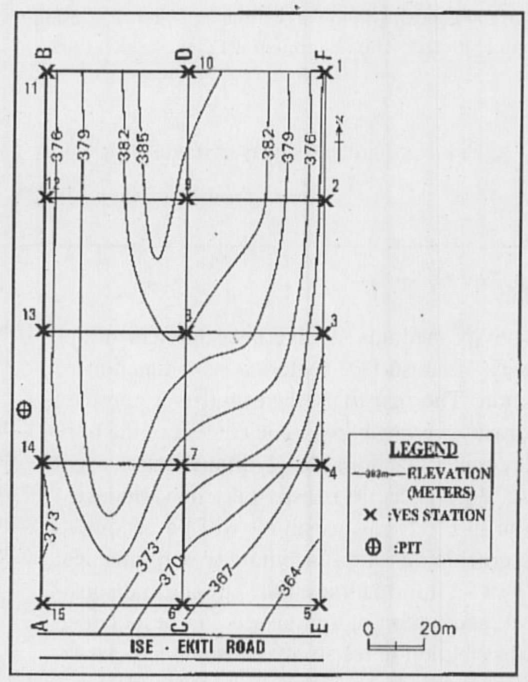

FIGURE 3. TOPOGRAPHICAL MAP OF THE AREA SHOWING THE VES STATIONS.

TABLE 1. VES INTERPRETED RESULTS.

VES STATION NUMBER	DEPTH (D_1 / D_2 / D_3 / . . . / D_n) (m)	LAYER RESISTIVITY (ρ_1 / ρ_2 / ρ_2 / . . . / ρ_n) (ohm-m)	CURVE TYPE
1	0.86 / 1.73 / 3.7 / 34	620 / 395 / 975 / 105 / ∞	HKH
2	1.18 / 4.47 / 10.3/ 40.2	358 / 1074 / 217 / 116 / ∞	KQH
3	0.75 / 10.5 / 30.0	520 / 636 / 130 / ∞	KH
4	1.08 / 4.43 / 13.5 / 60	380 / 242 / 480 / 105 / ∞	HKH
5	0.95 / 7.41 / 8.70/ 71.1/ 106	190 / 285/ 52 / 115 / 131/ ∞	KHKH
6	0.84 / 11.5 / 70.2	190 / 1350 / 165 / ∞	KH
7	1.1 / 14.2 / 70.46	220 / 440 / 105 / ∞	KH
8	1.43 / 5.29 / 29.8 / 73.92	325 / 163 / 300 / 172 / ∞	HKH
9	1.41 / 106 / 63.48	180 / 420 / 205 / 4370	KH
10	1.43 / 14.73 / 58.62	230 / 427 / 210 / 9750	KH
11	1.38 / 17.94 / 49.40	20 5/ 615 / 331 / 8740	KH
12	1.12 / 15.68 / 69.55	300 / 700 / 361 / ∞	KH
13	1.5 / 13.8 / 90.36	1150 / 1406 / 156 / 7020	KH
14	1.36 / 7.5 / 95.2	150 / 1350 / 485 / 9120	KH
15	0.72 / 7.2 / 78.5	318 / 389 / 206 / ∞	KH

TABLE 2. ESTIMATION OF VOLUME OF KAOLIN FROM ISOPACH MAP.

BLOCK	NUMBER OF SOUNDING POINT/SAMPLE CONTOUR LINE	THICKNESSES FROM CONTOUR LINE/VES STATION (m)	MEAN THICKNESS (m)	AREA OF BLOCK (m^2)	VOLUME OF KAOLIN (m^3)
SQ1	14	33,34,36,38,40,42, 44,46,48,50, 51.5,52,54.5.	40.64	2500	101,607.14
SQ2	16	54.5,51.5,67.5, 76,74,72,70,72, 74,76,78,80,82,83.	62.84	2500	157,100
SQ3	14	60,61,64,66,67.5, 68,70,72,74,76,78, 80,82,83.	71.61	2500	179,017.86
SQ4	14	60,62,64,66,68, 70,71.5,72,74,76, 78, 80,82,83.	71.89	2500	179,732.14
SQ5	14	31,31.5,32,34,36, 38,39,40,42,44,46, 48,50,51.5.	40.21	2500	100,535.71
SQ6	28	19,20,22,24,26,28, 30,31.5,32,34,36, 38,40,42,44,46,48, 50,51.5,52,54,56, 58,60,62,64,66,67.5.	42.91	2500	107,276.79
SQ7	28	19,20,22,24,26,28, 30,32,34,36, 38,40,42,44,46,48, 50,52,54,56, 58,60,62,64,66,67.5.	43.01	2500	107,548.08
SQ8	28	46,48,50,52,54,56, 58,60,62,64,66,68, 70,72,74,76,78,80, 82,84,86,88,90,92, 94,96,98,99.5.	72.96	2500	182,410.71

TOTAL VOLUME: 1,115,228.43m^3

TABLE 3. ESTIMATION OF VOLUME OF OVERBURDEN FROM ISOPACH MAP.

BLOCK	NUMBER OF SOUNDING POINT/SAMPLE CONTOUR LINE	THICKNESSES FROM CONTOUR LINE/VES STATION (m)	MEAN THICKNESS (m)	AREA OF BLOCK (m^2)	VOLUME OF KAOLIN (m^3)
SQ1	7	17.5,15,12,16,17, 14,13.	14.93	2500	37,321.43
SQ2	10	7,8,9,10,11,12,132,14,15,16.	11.5	2500	28,750.00
SQ3	11	7,7.5,8,9,10,11,12, 13,14,14.5,15.	10.97	2500	27,431.82
SQ4	11	7,7.5,8,9,10,11,11.5,12, 13,15.	10.68	2500	26,704.55
SQ5	12	4,5,6,7,8,9,10,11,12, 13,14,15.	9.5	2500	23,750.00
SQ6	6	7,8,9,10,11,12.	9.5	2500	23,750.00
SQ7	9	7,8,9,10,11,12,13,14, 14.5.	10.94	2500	27,361.11
SQ8	10	7.5,8,9,10,11,11.5, 12,13,14,14.5.	9.9	2500	24,750.00

TOTAL VOLUME: 219,818.91m^3

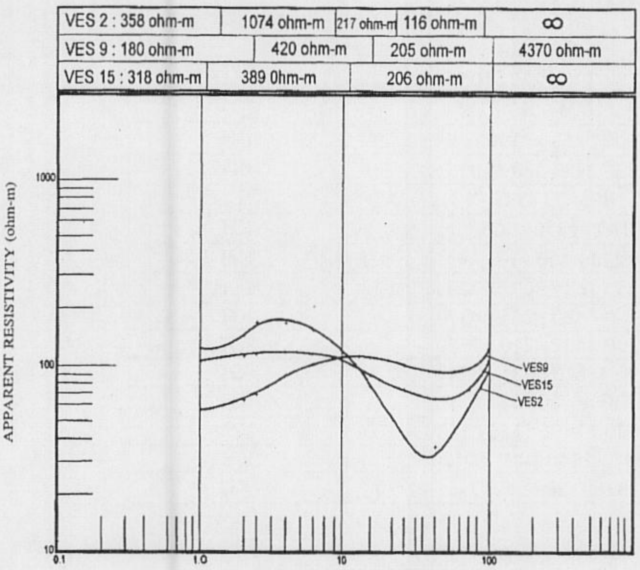

Figure 4. Typical depth sounding curves for the area of study.

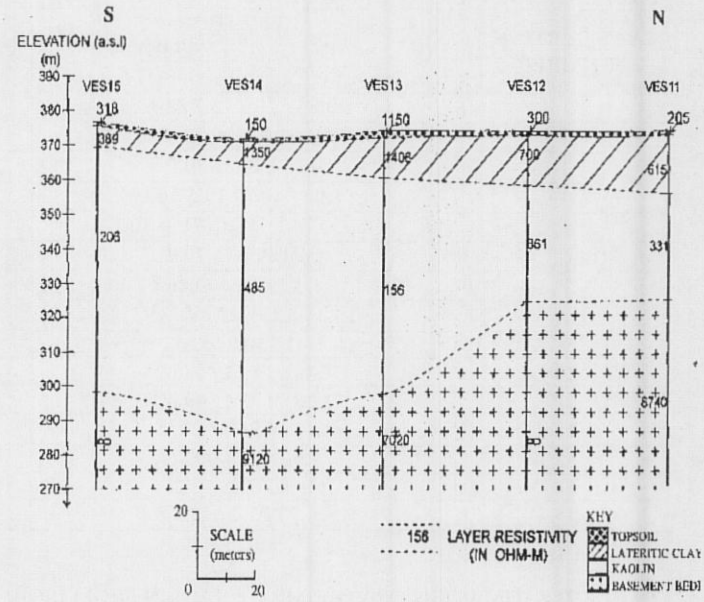

FIGURE 6. THE GEOELECTRIC SECTION ALONG TRAVERSE 1

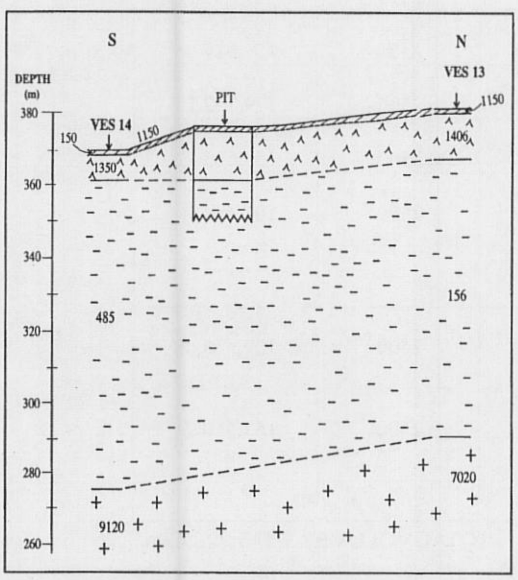

FIGURE 5: CORRELATION OF VES INTERPRETATION RESULT (VES 14 AND 13) WITH PIT LITHOLOGICAL LOG.

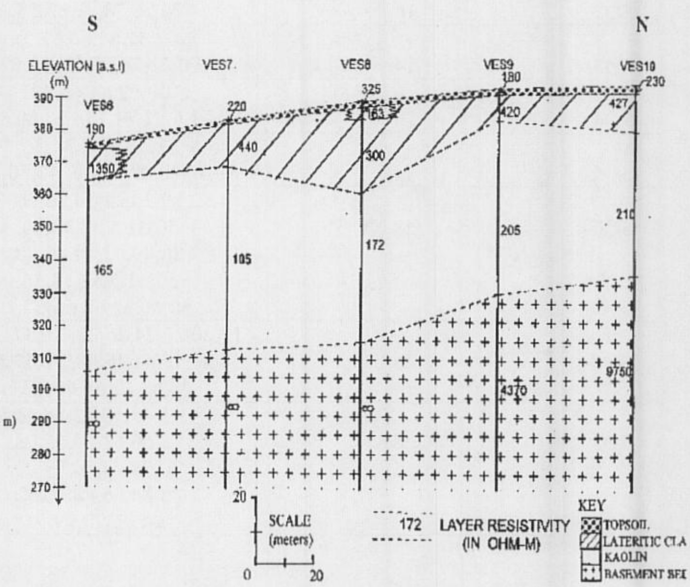

FIGURE 7. THE GEOELECTRIC SECTION ALONG TRAVERSE 3

$$d_s = \frac{W_s}{W_s - (W_T - W_w)} \qquad (1)$$

where d_s, W_s, W_w, W_T are density of sample, weight of air-dried sample, weight of water and density bottle and weight of bottle with water and air-dried sample respectively.

The average value of the density calculated was used in the determination of the reserve (tonnage) of the kaolin deposit. The volume of the excavable overburden was calculated in a like manner, as for the volume of kaolin deposit.

4. Results and Discussion

Three geoelectric sections were drawn along traverses 1,2,3 all trending in the north – south direction. The geoelectric section along traverse 1 (A – B) in Fig. 6, shows four distinct layers namely topsoil, lateritic clay, kaolin and basement. The topsoil has thicknesses varying from about 0.7m to 1.5m while its resistivity values vary from 150 to 1150 ohm-m. The second layer is lateritic clay with resistivity values ranging from 389 to 1350 ohm-m and thicknesses ranging from about 5m to 15m. The third layer is the kaolin deposit. The layer resistivity values vary from 156 – 485 ohm-m. While the thickness varies from 32m to 83m. The fourth layer is the basement bedrock with resistivity values of 7020 ohm-m and above.

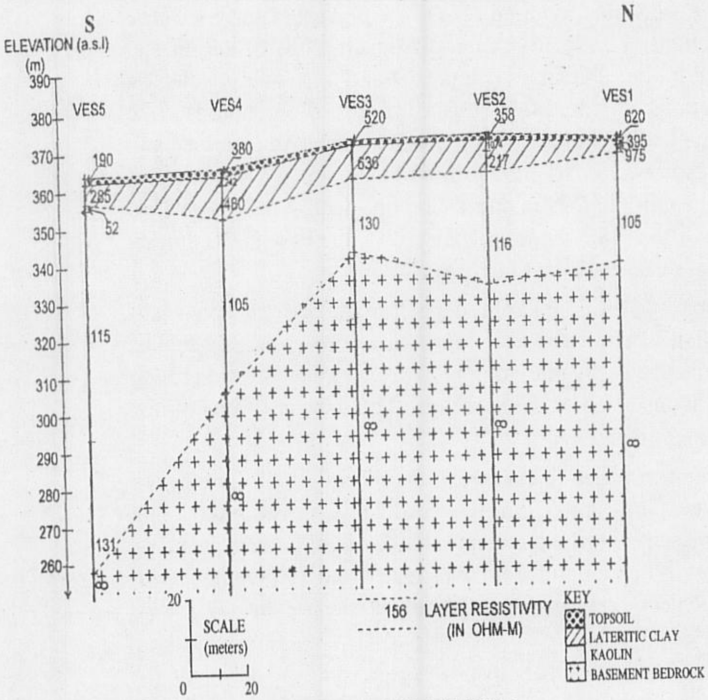

FIGURE 8. THE GEOELECTRIC SECTION ALONG TRAVERSE 5

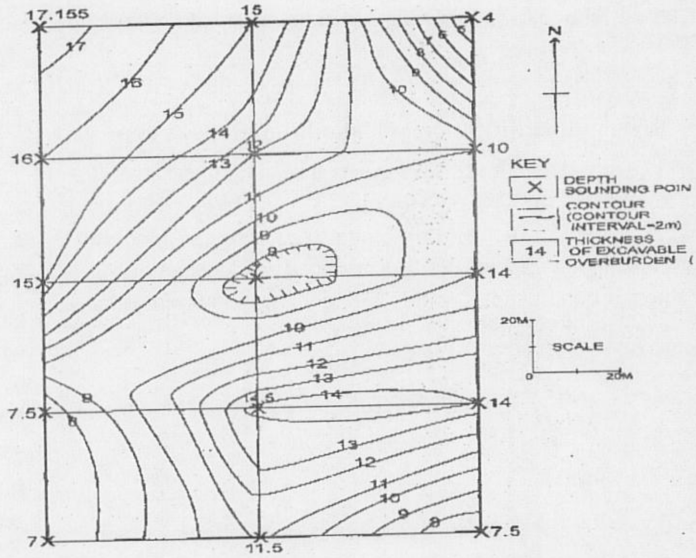

FIGURE 10. ISOPACH MAP OF OVERBURDEN

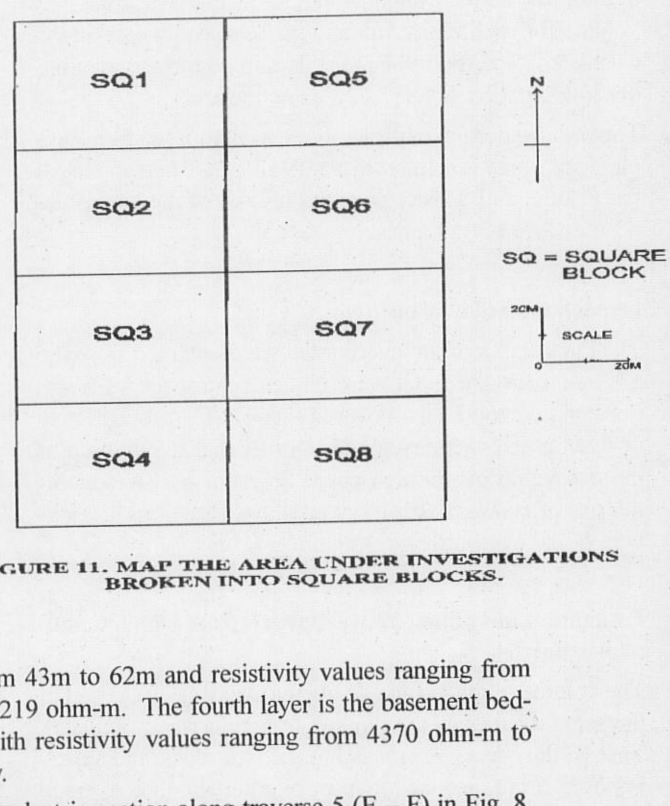

FIGURE 11. MAP THE AREA UNDER INVESTIGATIONS BROKEN INTO SQUARE BLOCKS.

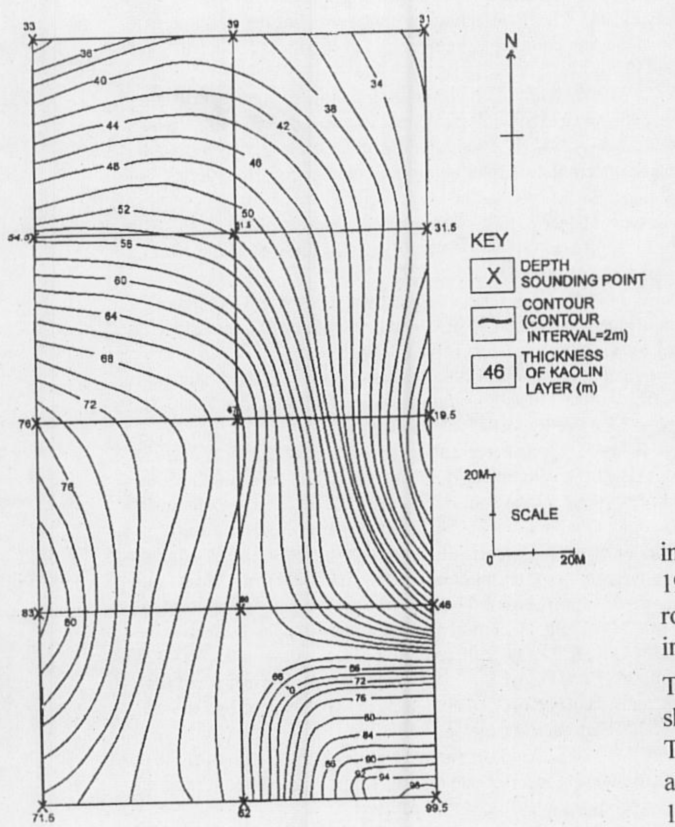

FIGURE 9. ISOPACH MAP OF KAOLIN

The geoelectric section along traverse 3 (C – D) in Fig. 7, also shows four geoelectric layers. The first layer is the topsoil with thicknesses varying from 0.8m to1.4m while its resistivity values vary from 190 to 325 ohm-m. The second layer is lateritic clay with resistivity values ranging from 163 to 1350 ohm-m and thicknesses ranging from 5m to 13m. The third layer is kaolin deposit with thicknesses varying from 43m to 62m and resistivity values ranging from 195 to 219 ohm-m. The fourth layer is the basement bedrock with resistivity values ranging from 4370 ohm-m to infinity.

The geoelectric section along traverse 5 (E – F) in Fig. 8, shows four geoelectric layers, just like the first two above. The first layer, which is the topsoil, varies in thickness from about 0.8m to 1.2m while its resistivity values range from 190 – 620 ohm-m. The second layer is lateritic clay having resistivity values, which range between 217 and 1074 ohm-m. The thickness of the lateritic clay varies between 3m and 13m. The third layer is kaolin with layer resistivity values varying from 105 to 131 ohm-m and thicknesses of between 19m and 99.5m. The fourth layer is the basement bedrock with an infinite resistivity.

Isopach map of kaolin deposit

The thicknesses of the kaolin obtained from the VES interpretation results were plotted against the VES stations and contoured as shown in Fig. 9. A 2m contour interval was used. The map shows variation in thickness of kaolin from 19m to 99.5m.

Reserve quantification of kaolin from isopach map

The site under investigation has a rectangular shape. The rectangle was broken into eight square blocks (Fig. 11). The average thickness of kaolin in each square block was calculated from the VES determined thicknesses and values of contour lines within the block as shown in Table 2 from the Equation 2.

$$h_B = \frac{\sum_1^N h_N}{N} \quad (2)$$

where, h_B, h_N, N are average thickness of deposit per block, value on the *n*th isopach contour within the block and the number of contours running across the block respectively.

Table 2 shows the estimated kaolin thicknesses, areas and volume for each block unit and the total volume of kaolin calculated. The total volume of kaolin within the area under investigation is 1,115,228 cubic meters.

The average density of the kaolin was determined from simple displacement method to be 2.45g/cm^3. The product of the volume and density gave the reserve of the kaolin deposit as 2,732,305 tonnes.

Isopach map of overburden

The thicknesses of the overburden were obtained from the VES data and the result were plotted against the VES stations and contoured as shown in Fig. 10. The isopach map of overburden was developed in order that the volume of the excavable overburden could be estimated. A contour interval of 1m was used. The map shows variations in thickness of the overburden from 4m to 17.5m.

Estimation of volume of overburden from isopach map of overburden

The volume of the excavable overburden was calculated in the same manner as the volume of kaolin was calculated. That is, the survey area was broken into block and superimposed on the isopach map of overburden. The average thickness per block was determined from the contour values and VES results. The summation of the product of the area of each block and the average thickness (Table 3) gave the volume of the excavable overburden as 219,818.91m^3.

Conclusion

This paper describes the electrical resistivity survey of the Ikere kaolin deposit. The survey involved a total of 15 Schlumberger vertical electrical resistivity soundings (VES) uniformly distributed within the survey area. The electrode separation (AB/2) varied from 1m to 100m. The vertical electrical sounding (VES) data were presented as VES curves interpreted quantitatively by partial curve matching and computer aided iterative technique using Resist software.

The VES interpretation results are presented as geoelectric sections (Figures 6 – 8) and isopach maps of kaolin and overburden thickness (Figures 9 and 11). The geoelectric sections identified four subsurface layers – topsoil, lateritic clay, kaolin and the basement. The layer thicknesses and resistivities for the upper three layers are 0.7 – 1.5m; 3 – 15m and 19 – 99.5m and 1150 ohm-m; 163 – 1406 ohm-m and 105 – 485 ohm-m respectively. The basement bedrock is in most places infinitely resistive.

The reserve of the kaolin deposit in the area under investigation is estimated to be approximately 2,732,305 tonnes while the excavable volume of overburden is estimated to be about 219,819 cubic meters. The deposit can be mined economically.

The overburden thicknesses range from 4 to 17.5m, hence surface mining technique could still be adopted. The geoelectric sections indicate that the kaolin layer probably extends beyond the area investigated. Therefore, the kaolin deposit could be investigated beyond the present study area.

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