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# A Resistivity Survey of Phosphate Nodules in Oshoshun, Southwestern Nigeria

## Raziskava Upornosti Nahajališča Fosfatnih Gomoljev v Oshoshunski Formaciji v Jugozahodni Nigeriji

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## Abstract

This geophysical study was carried out to determine the occurrence of phosphate nodules in the Oshoshun Formation of the Dahomey Basin, Southwestern Nigeria. The electrical resistivity method, comprising 1D vertical electrical sounding (VES; using Schlumberger array) and 2D geoelectrical imaging (using Wenner array), was used to determine the nature and depth of occurrence of the phosphate nodules. Six profile lines were established within the study area, and inverted sections were generated from the apparent resistivity data using DIPRO inversion algorithm. Five VES points were also acquired in the study area, and WinResist programme was used to process and interpret the field resistivity data. Four pits were dug along the profiles to verify the interpreted results. The results obtained by both techniques reveal similar geoelectric units: the top soil, clay, clayey sand and clay at different depths. These layers host pockets of phosphate nodules (78–≥651 Ωm) with varying thicknesses. The strong correlation between the lithology profiles obtained from the pits and the interpreted results of the inverted apparent resistivity sections demonstrates the efficacy of the electrical resistivity method in characterising phosphate occurrence within the formation.

**Key words:** imaging • inversion • Oshoshun • phosphate nodules • resistivity

## Povzetek

Namen te geofizikalne raziskave je bil opredeliti nahajališče fosfatnih gomoljev v oshoshunski formaciji dahomejske kadunje v jugozahodni Nigeriji. Z uporabo metode električne upornosti so določili naravo in globino nahajališča fosfatnih gomoljev, in sicer z 1D vertikalnim električnim sondiranjem ob uporabi Schlumbergerjevega razporeda in z 2D geoelektrično preiskavo z Wennerjevim razporedom. Na raziskovanem območju so izmerili šest profilov in izdelali iz podatkov navidezne upornosti prognozne preseke ob uporabi inverzijskega algoritma DIPRO. Na proučevaneem ozemlju so izvedli tudi pet vertikalnih električnih sondiranj (VES). Za obdelavo in interpretacijo terenskih meritev upornosti so uporabili program WinResist. Za preverbo interpretiranih rezultatov so izkopali ob profilih štiri jaške. Rezultati obeh postopkov so podobni, razkrivajo navzočnost vrhnjih tal, gline in glinenega peska v različnih globinah. V teh plasteh so žepi fosfatnih gomoljev (78 - ≥651 Ωm) različne debeline. Visoka stopnja ujemanja med litološkimi podatki iz jaškov in rezultati iz interpretiranih profilov navidezne upornosti priča o učinkovitosti električne upornostne metode za ugotavljanje fosfatnih nahajališč v plasteh.

**Ključne besede:** sondiranje, interpretacija, oshoshunska formacija, fosfatni gomolji, upornost

## Introduction

Phosphate rock is a globally accepted but imprecise term describing any naturally occurring geological material that contains one or more phosphate minerals suitable for commercial use. The rock comprises both the unprocessed phosphate ore and the concentrated phosphate products [1]. The phosphorus content or grade of phosphate rocks is commonly reported as phosphorus pentoxide ($P_2O_5$). The principal phosphate minerals in phosphate rocks are calcium phosphates, mainly apatites. Five major types of phosphate resources are being mined in the world: marine phosphate deposits, igneous phosphate deposits, metamorphic deposits, biogenic deposits and phosphate deposits as a result of weathering [2]. Sedimentary phosphates are of great economic importance because they constitute most of the raw materials for the manufacture of phosphate fertiliser and some phosphorus-based chemicals. Direct application of phosphate rock as phosphate fertiliser has been found to compete favourably well with mineral fertilisers on acidic soils [3–6]. Electrical resistivity surveys have been conducted on some phosphate deposits, and remarkable results have been achieved [7,8].

There are large deposits of phosphate-rich sediments of the Eocene Age in Ogun State of Southwestern Nigeria. Although the slightly older (Paleocene) phosphate deposits of Sokoto State have been extensively worked for agricultural material, the Ogun phosphate rock has received little attention [9,10]. It is important to carry out geophysical characterisation studies of Ogun phosphate rock to ascertain the availability of phosphates. Therefore, this study was carried out to determine the occurrence of phosphate nodules and evaluate the nature and depth of such phosphate beds in the study area.

## Location and geology of the study area

The study area is located in Oshoshun village, in Ifo local government area of Ogun State. It is located within the longitudes 7°27′14.1″, 7°27′12.5″, 7°27′07.9″ and 7°27′12.6″ and the latitudes 3°53′40.4″, 3°53′40.7″, 3°53′27.6″ and 3°53′36.5″ (Figure 1). The area is accessible through an untarred road, which branches off from the Lagos–Abeokuta Express Road.

The study area lies within the Oshoshun Formation, which is phosphate bearing. The phosphate within the Oshoshun occurs as discrete bands in the shale, which sometimes at some parts could also be glauconitic, while the gypsum appears as mud-supported gypsiferous

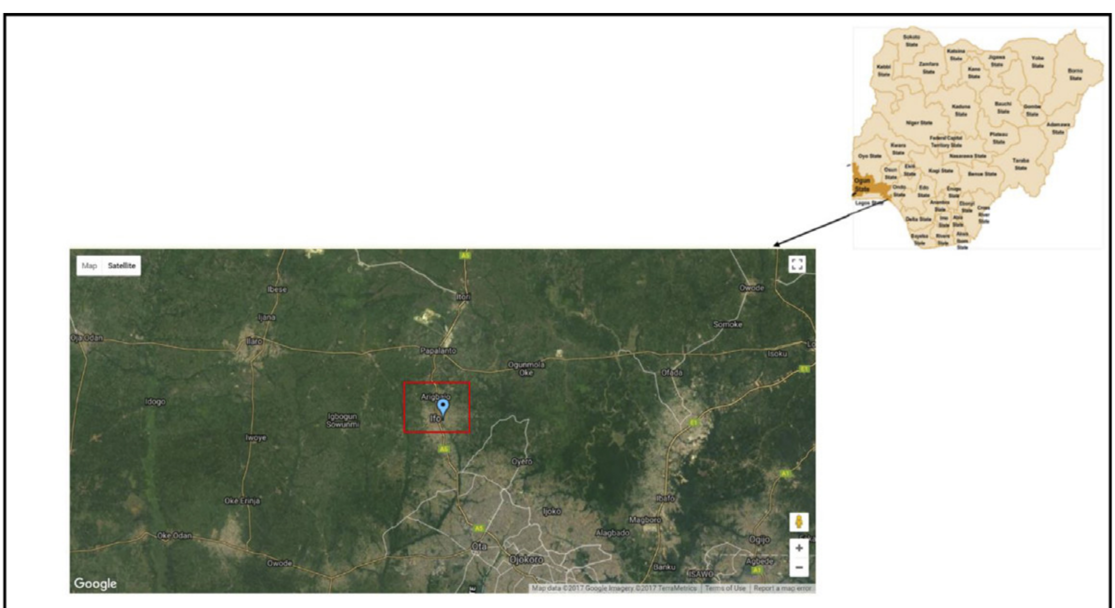



**Figure 1:** *Map of Nigeria showing the Ifo local government area and its environs.*

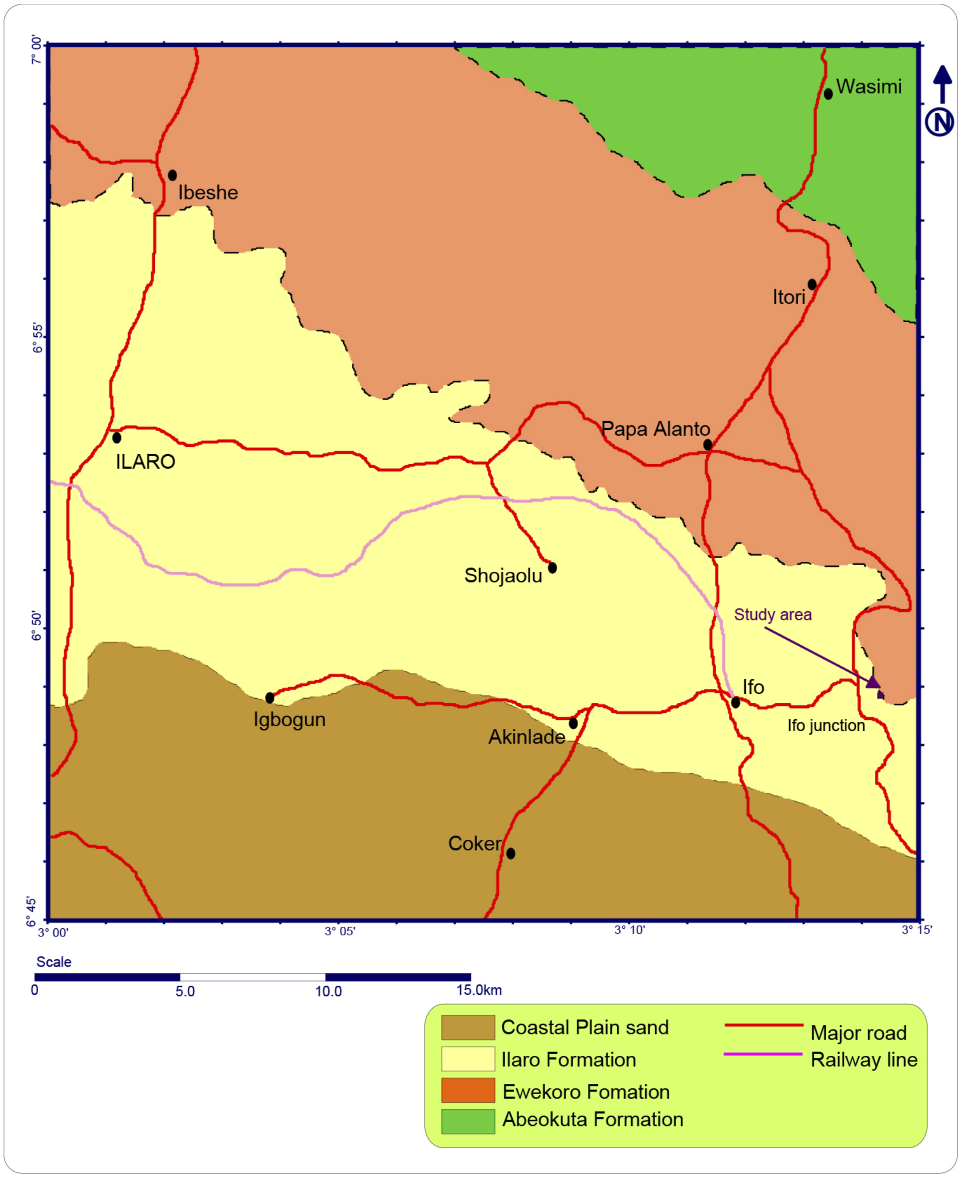



**Figure 2:** *Geological map of Ifo and environs showing the study area.*

shale. The Oshoshun is overlain by the Ilaro Formation, which is made up of both marine and continental massive yellow and poorly consolidated sandstones (Figure 2). The phosphates occur as nodules at ~3–6 m of depth within the formation.

## Methodology

### *Electrical Resistivity Surveys*

Six 2D geoelectrical resistivity profile lines were measured (Figure 3) with the aid of an Ohmega Campus model resistivity meter using the Wenner-alpha array. Each of the 2D traverses was 50 m in length, and they formed an orthogonal set such that the total area covered by the 2D traverses was ~2500 $m^2$. Five vertical electrical sounding (VES) data were also collected in the site using Schlumberger array to supplement the observed 2D resistivity imaging data and to provide layering information on the lithology of the study area. Figure 3 shows the survey plan with the locations of the traverses and the VES points. The measurements commenced at the east end for the in-lines and at the north end

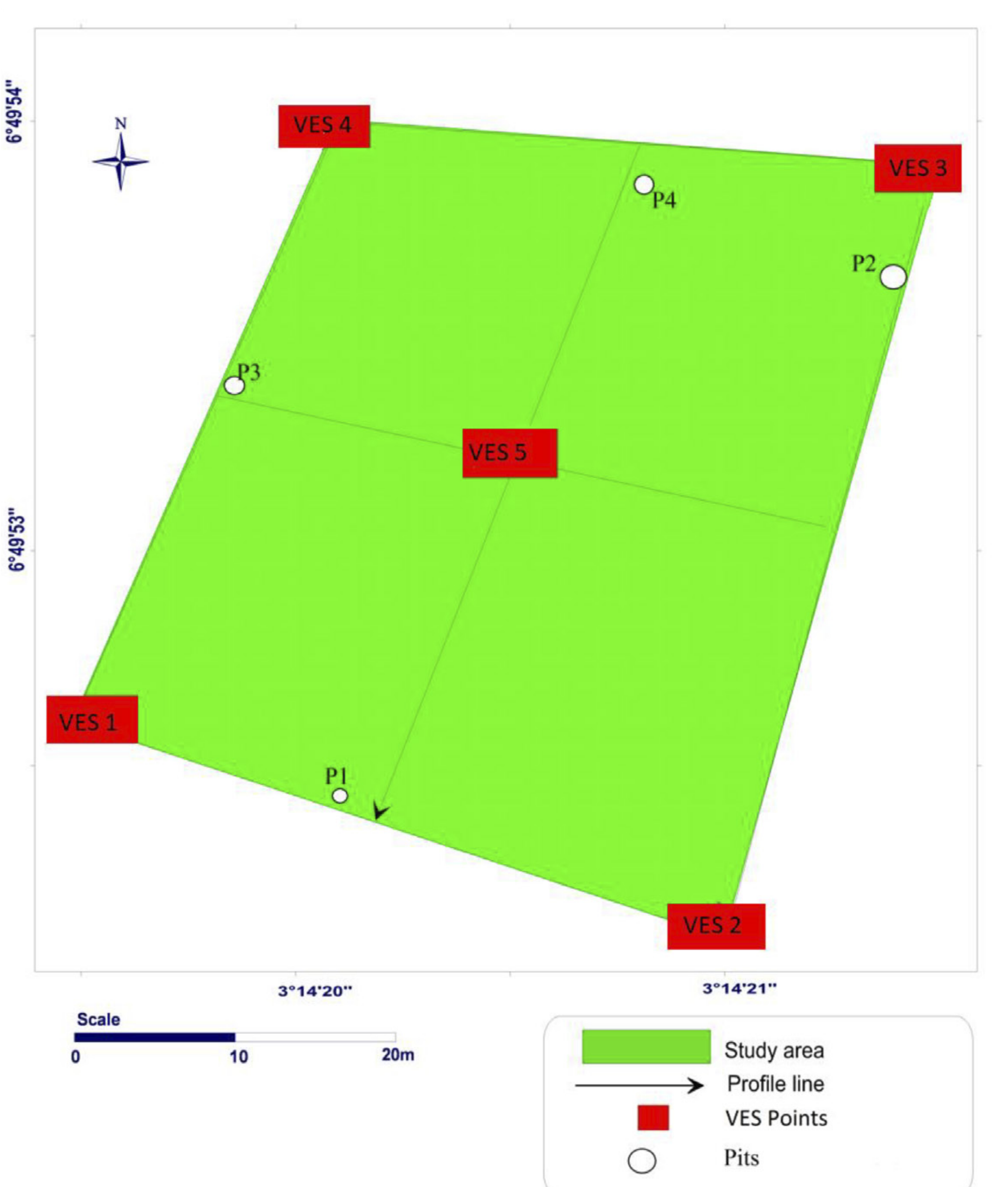



**Figure 3:** *Map of the study area showing locations of geophysical 1D (VES) and 2D resistivity imaging lines (Profiles 1, 2, 3, 4, 5 and 6) surveys.*

for the cross-lines. Four pits were dug along the profiles 1, 2, 4 and 6 (Figure 3) to verify the interpreted results.

### *Data Processing and Inversion*

The electrical imaging data was processed and interpreted using computer-assisted DIPRO software and presented as inverted sections. The VES curves were quantitatively interpreted by partial curve matching and computer-assisted 1D forward modelling with the WinResist software, version 1.0 [11].

## Results and Discussion

### *Geoelectric Profiles*

Figure 4 shows a system of three geoelectric layers from the inverted section. The top soil has resistivity values ranging from 52 to 85 Ωm

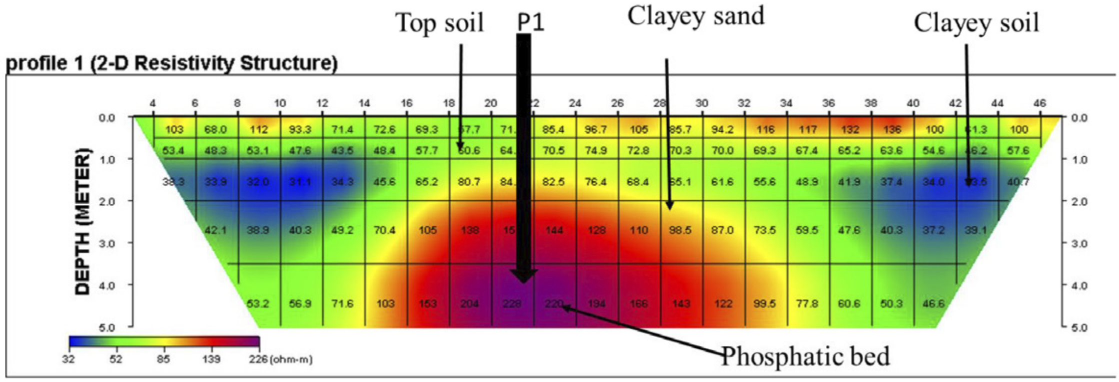



**Figure 4:** *Inverted model section of Profile line 1.*

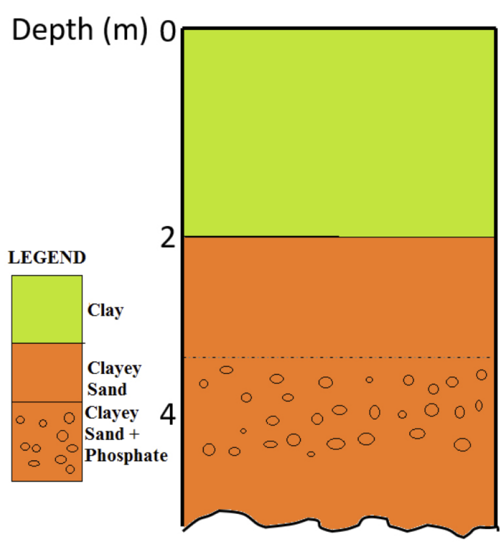



**Figure 5:** *Soil profile of Pit 1 (P1) dug along Profile 1.*

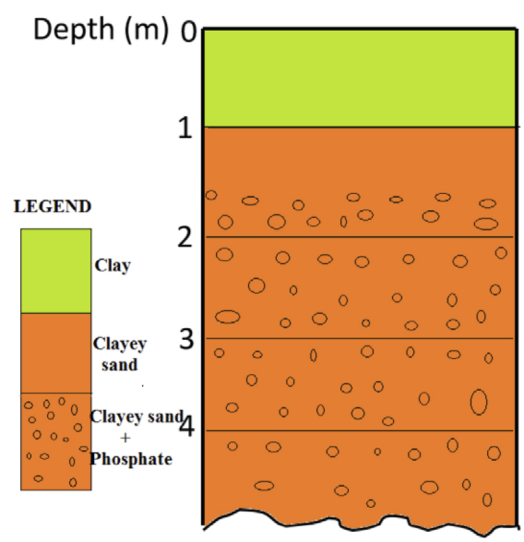



**Figure 7:** *Soil profile of Pit 2 (P2) dug along Profile 2.*

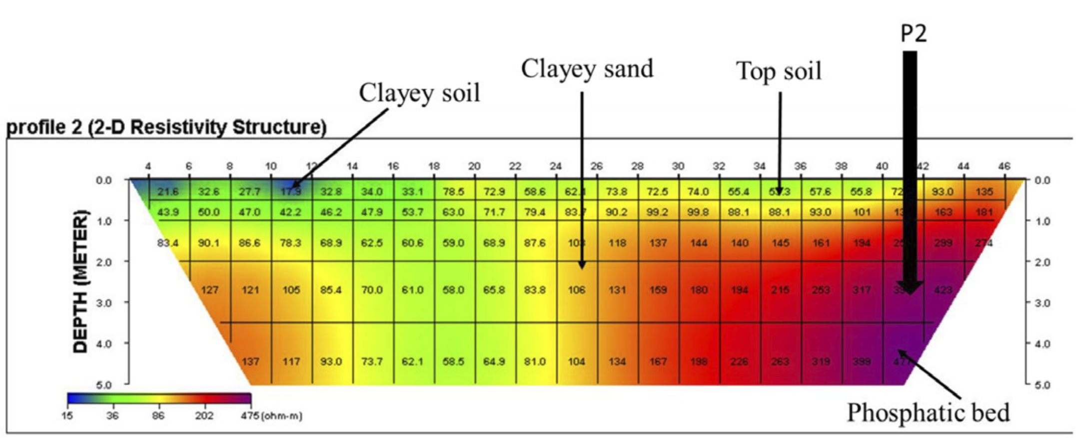



**Figure 6:** *Inverted model section of Profile line 2.*

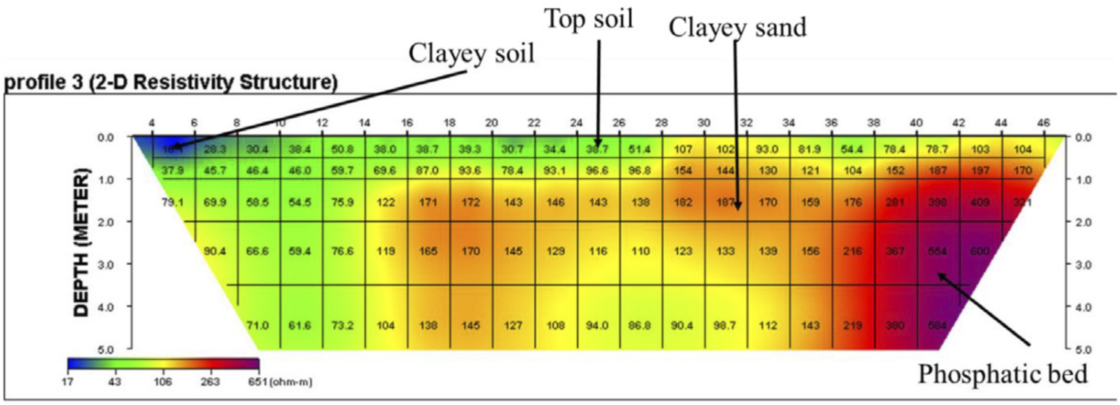



**Figure 8:** *Inverted model section of Profile line 3.*

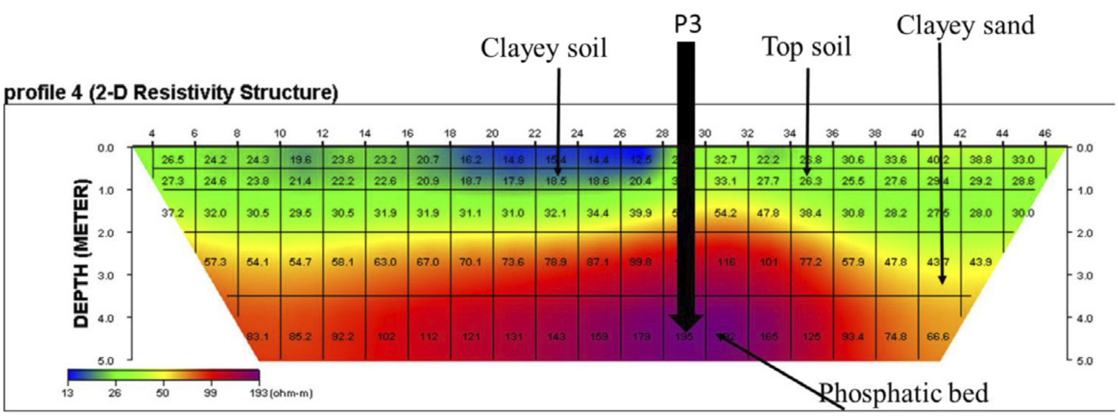



**Figure 9:** *Inverted model section of Profile line 4.*

extending from the surface to an average depth of 1.0 m; the next layer has resistivity values between 32 and 52 Ωm. This lithology is characterised by the presence of clayey material [12]. The clayey material occurs at both flanks of the traverse line. The third layer has resistivity values increasing from 63 to ≥ 139 Ωm. This indicates the presence of clayey sand [12]. The phosphate-nodule bed (139–≥226 Ωm) occurs within the clayey sand materials in the central lower part of the section.

The lithological column (Figure 5) of Pit 1 dug along Profile 1 reveals two horizons comprising clay (0.1–2 m thick) and clayey sand (2–> 5 m). Phosphate nodules are encountered at ~3.2 m within the clayey sand horizon. This result corresponds with the interpretation of the inverted section.

As observed from the 2D resistivity model in Figure 6, three varying geoelectric layers are

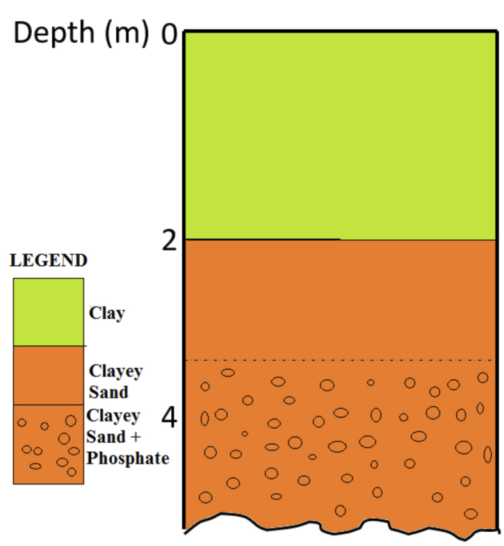



**Figure 10:** *Soil profile of Pit 3 (P3) dug along Profile 4.*

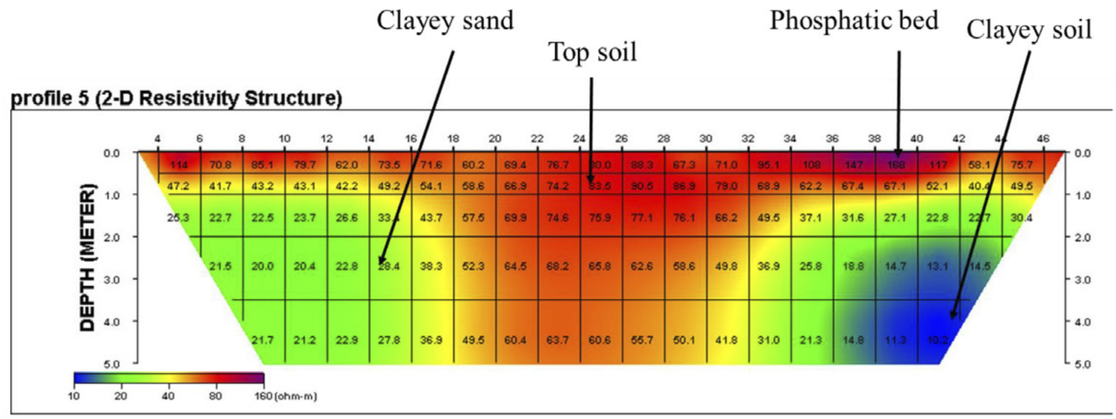



**Figure 11:** *Inverted model section of Profile line 5.*

detected. The resistivity values of the top soil are between 36 and 86 Ωm, as seen at the beginning of the profile up to the station at distance of 18 m, with an average depth of 1.5 m. The clayey soil layer has resistivity varying from 15 to 36 Ωm between stations at distances of 3 and 12 m. The clayey sand extends to the surface between stations at distances of 42 and 48 m, and its resistivity ranges from 86 to ≥ 202 Ωm; the phosphatic bed (202–≥475 Ωm) is embedded in this layer.

The soil profile (Figure 7) of Pit 2 dug along Profile 2, depicts two layers composed of clay and clayey sand. Phosphate nodules are embedded in the clayey sand at a depth of 1.5–≥4 m. This result corroborates the interpretation from the inverted section.

Profile 3 (Figure 8) shows an ordered arrangement of the geoelectric layers, although the layers tend to dip slightly at an angle. The top soil has resistivity value in the range of 43–106 Ωm, its horizontal extension being between 8 and 28 m. The underlying lithology is suggested to be clayey based on its resistivity value (17–43 Ωm), also occurring at the surface between stations at distances of 3 and 8 m. The clayey sand layer has resistivity values ranging from ≤ 106 to ≥ 263 Ωm. The phosphate-rich sequence is embedded within this layer, thus having resistivity value from 263 to ≥ 651 Ωm. The phosphatic nodule is concentrated at profile distances of 40–46 m.

The inverted section of Profile 4 (Figure 9) exhibits an ordered internal arrangement of the geoelectric layer, and its resistivity value increases with depth. Three geoelectric layers are observed in the inverted section; these include the top soil, clayey soil and clayey sand. The top soil shows that material of low resistivity (14–25 Ωm) is enclosed within a more resistive layer (25–33 Ωm); it extends to an average depth of 2.6 m. The clayey soil has resistivity value between 33 and 59 Ωm, and its thickness is ~1.2 m. The next layer underlying the clayey soil is depicted to be clayey sand, with its resistivity value varying from 59 to ≥ 103 Ωm. This layer hosts the phosphate concentrate (78–≥103 Ωm).

The soil profile (Figure 10) of Pit 3 dug along Profile 4 shows two layers made up of clay and clayey sand. Phosphate nodules are embedded in the clayey sand at a depth of 3.5–≥5 m. This result agrees with the interpretation of the inverted section in Figure 9.

Figure 11 (Profile 5) shows chaotic distribution of resistivities when compared with the distribution in other profiles (1–4): it is characterised by decrease in resistivity values as the depth increases. The top soil is composed of moderate resistive material (40–≥80 Ωm), with pockets of resistive material occurring at the surface. These pockets are referred to as the phosphate nodules. The phosphatic bed has resistivity between 80 and >160 Ωm occurring at stations at distances of 37–40 m. The clayey soil underlying the top soil has resistivity value ranging from 10 to 20 Ωm. The next layer is clayey sand having resistivity between 20 and >40 Ωm.

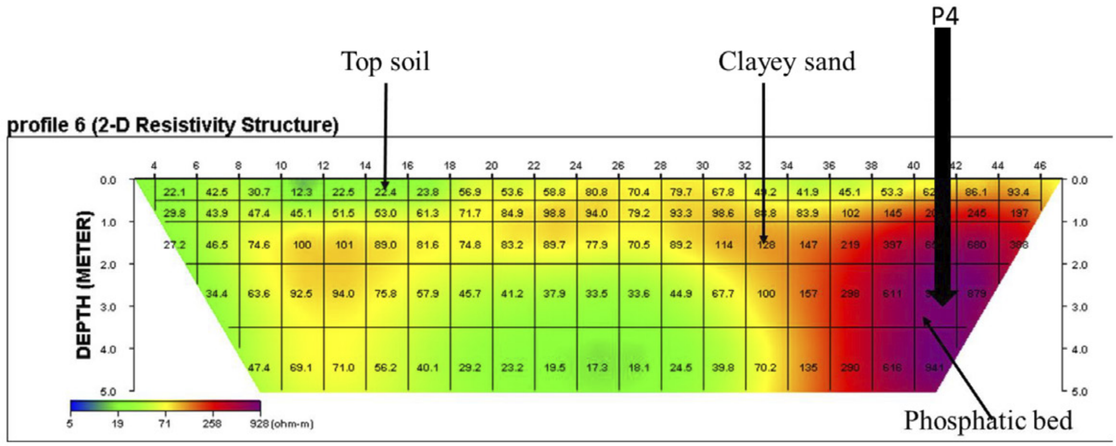



**Figure 12:** *Inverted model section of Profile line 6.*

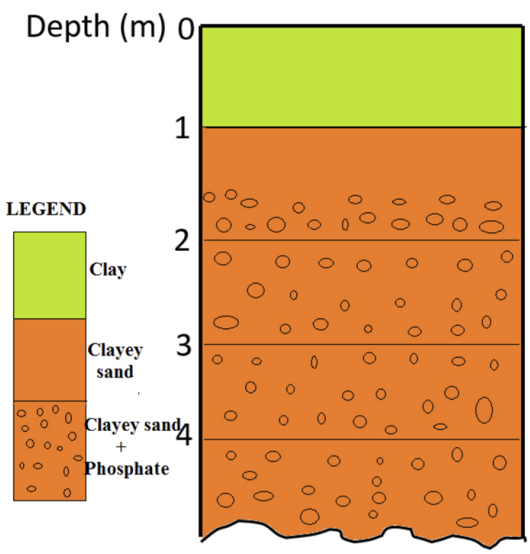



**Figure 13:** *Soil profile of Pit 4 (P4) dug along Profile 6.*

Profile 6 (Figure 12) shows the gradual transition of one lithology into another as can be assumed from the changing resistivity values horizontally along the profile. The top soil is characterised by resistivity values in the range of 19–71 Ωm. A resistive body is embedded with the clayey sand layer: this resistive body is suspected to be composed of nodules of phosphate. The phosphatic nodules are concentrated at stations at distances of 38–45 m in the top soil.

The soil profile (Figure 13) of Pit 4 dug along Profile 6 reveals two layers made up of clay and clayey sand. Phosphate nodules are encountered in the clayey sand at depth of 1.5–≥5 m. This result agrees with the interpretation of the inverted section.

### *VES data*

The resistivity sounding curves of the five VES stations obtained from the study area have four layers, which are KH-type curves with $\rho_1 < \rho_2 > \rho_3 < \rho_4$ (Figure 14). The analysis and interpretation of the VES curves and the geoelectric parameters indicate that four layers are delineated, including top soil, clay unit, clayey sand and clay. Each litho-unit varies in thickness from one point to another within the study area (Figure 14A–E).

### *Geoelectric Sections*

The 2D view of the geoelectric parameters obtained from the VES data are presented as VES-derived geoelectric sections (Figures 15 and 16). The VES model resistivity values complement the inversion results of the 2D image by distinguishing four different layers.

### *Geoelectric section 1*

Figure 15 is deduced from the joint layer parameters of VES 1, 5 and 3. From the VES geoelectric section, the following layers are obtained: the top soil, clayey sand, clay and clayey sand. The top soil has resistivity value ranging from 62 to 67 Ωm, with an average thickness of 0.93 m. The next layer underlying this unit is clayey sand, its thickness ranges from 3.9 to 7.1 m and the resistivity value of this unit varies

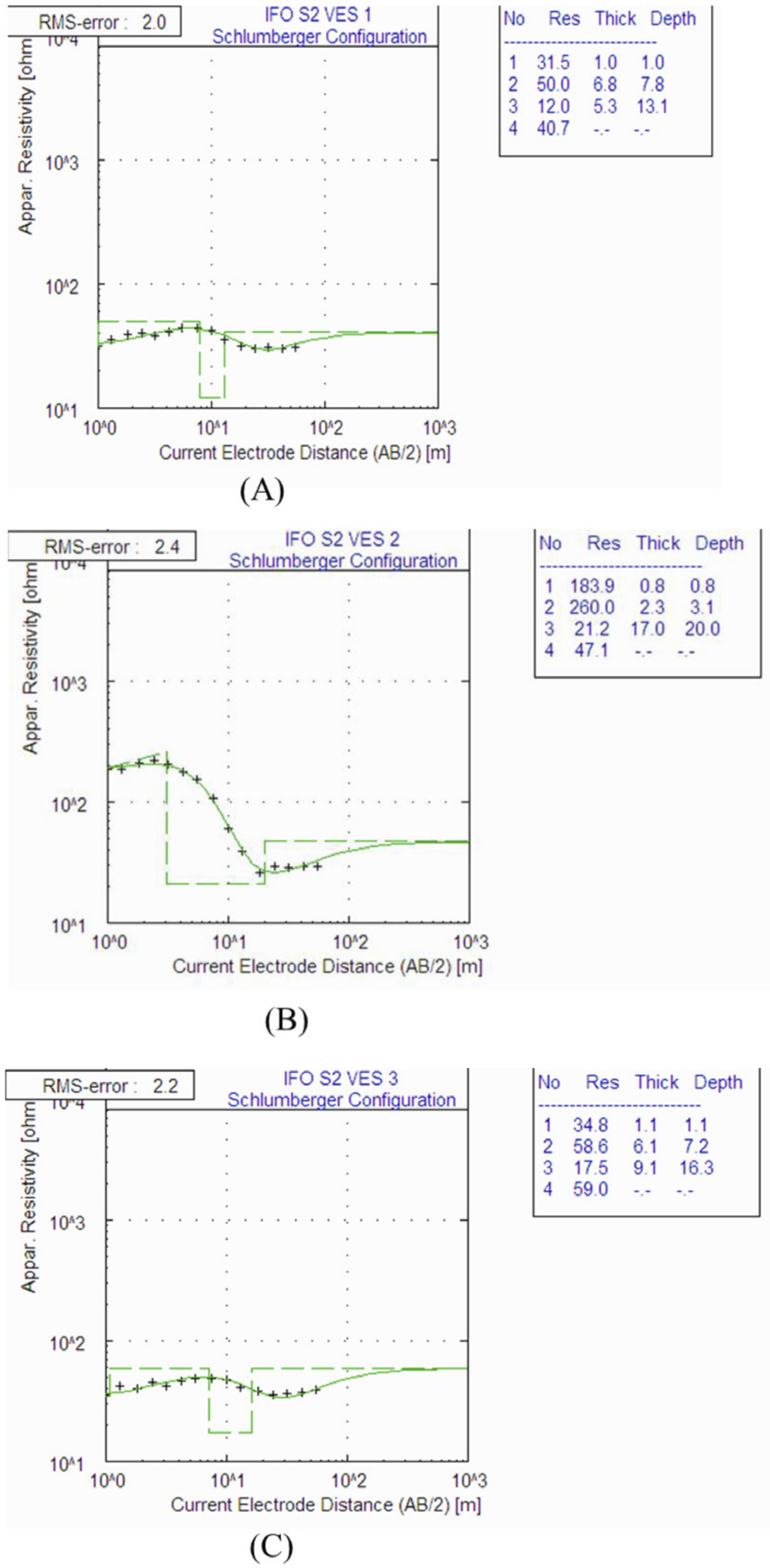
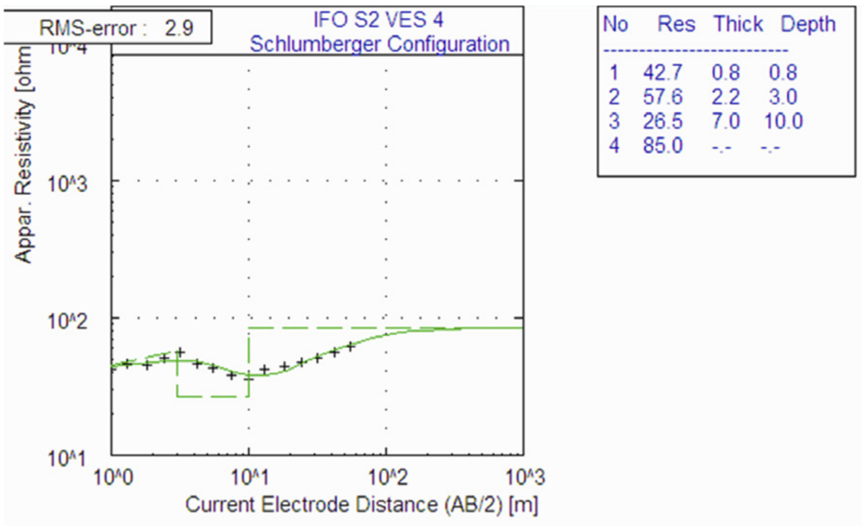
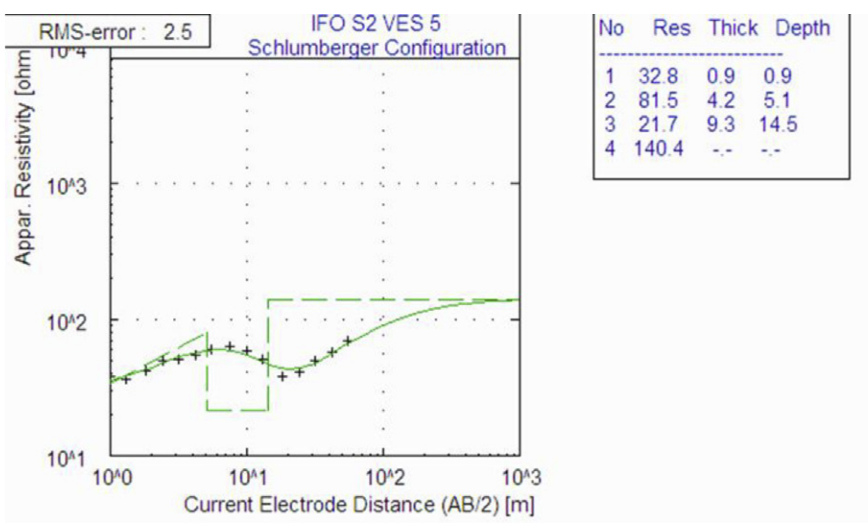



**Figure 14:** *Schlumberger layer model (A) VES 1; (B) VES 2; (C) VES 3 (all are representatives of KH-type curve: $\rho_1 < \rho_2 > \rho_3 < \rho_4$).*




(D)




(E)

**Figure 14:** *Schlumberger layer model (D) VES 4; and (E) VES 5 (all are representatives of KH-type curve: $\rho_1 < \rho_2 > \rho_3 < \rho_4$).*

from 51 to 82 Ωm. The clay unit has resistivity value ranging from 13 to 20 Ωm, it happens to be the thickest unit within this section and its thickness varies from 8.1 to 10.3 m. The last in the sequence is clayey sand; the resistivity value of this layer ranges from 55 to 158 Ωm, which extends from 13.2 m below the surface. The phosphate nodules are embedded within the clayey sand layer.

### *Geoelectric section 2*

The VES-derived geoelectric section (Figure 16) shows four geoelectric units; these include the top soil, clayey sand, the clay unit and clayey sand unit. These sequences tend to alternate with one another with varying thickness and resistivity values. The top soil has thickness ranging from 0.7 to 0.9 m, and the average thickness is 0.83 m. The resistivity value of this unit ranges from 30 to 34 Ωm. Next to this is the clayey sand, and its resistivity varies from 83 to 129 Ωm, with an average thickness of ~3.9 m. The clay unit has the greatest thickness when compared with other units, its resistivity value ranges from 13 to 21 Ωm, it has thickness value ranging from 9.4 to 11.8 m, and thus an

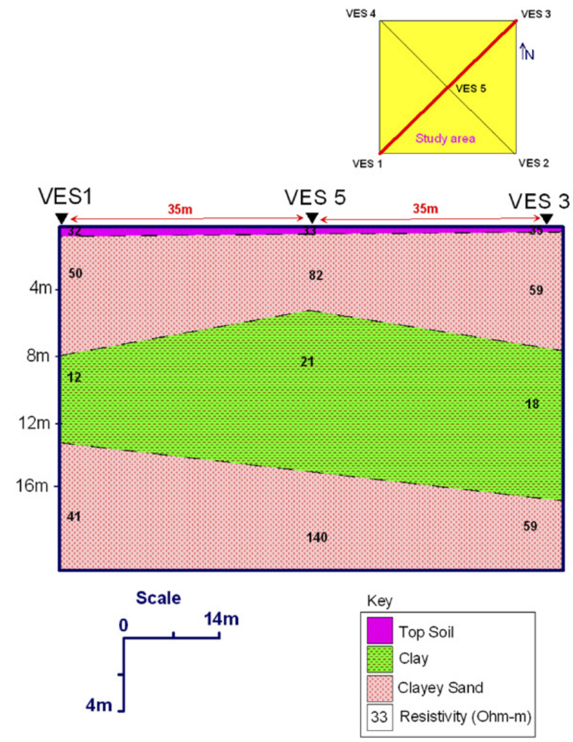



**Figure 15:** *VES-derived geoelectric section across VES 1, 5 and 3, respectively.*

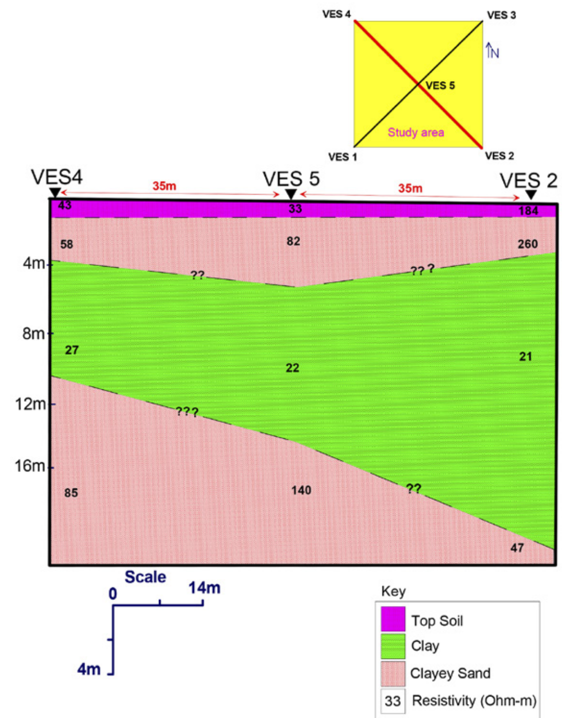



**Figure 16:** *VES-derived geoelectric section across VES 4, 5 and 2 respectively.*

average thickness of 10.5 m is computed for this unit. The clayey sand has resistivity value ranging from 80 to 130 Ωm and it extends from 13.7 m downwards. The phosphate nodules are also embedded within the clayey sand layer.

## Conclusions

Geophysical methods have proven to be effective in delineating the deposits of subsurface raw materials. An integrated geoelectrical study, comprising 1D and 2D resistivity surveys, was used to determine the occurrence of phosphate nodules in the Oshoshun Formation of Dahomey Basin, Southwestern Nigeria. The results obtained by both techniques reveal similar geoelectric units: top soil, clay, clayey sand and clay at different depths. In most cases, clayey sand layers host pockets of phosphate nodules (78–≥651 Ωm) with varying thicknesses. The observed resistivity values of the phosphate nodules at Oshoshun fall in the same range of resistivity values of phosphates from Morocco reported by Bakkali [7]. The strong correlation between the lithology profile obtained from the pits and the interpreted results of the inverted apparent resistivity section demonstrates the efficacy of the electrical resistivity method in characterising phosphate occurrence within the Oshosun Formation. Moreover, geophysical surveys have shown their advantages over other methods, such as drilling, digging pits, etc. Geoelectrical methods are non-destructive, they require short time to survey large areas and the associated costs are thereafter low. The use of geophysical methods is highly recommended in the early stages of reconnaissance for raw materials.

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