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Full Length Research

Two-dimensional image of seismic refraction tomography and electrical resistivity tomography survey in a proposed geophysical test site at Shika, Ahmadu Bello University Zaria, Nigeria

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ABSTRACT: Due to the advancement in technology being applied in geophysics, it is of importance that a geophysical test site center is established for calibration, training, and demonstration of such equipment. An integrated geophysical survey of the area has been conducted, with the aim of characterizing the subsurface structures and lithology. Thereafter, different types of objects that respond to all geophysical techniques will be buried at different depths in the site. Seismic refraction and electrical resistivity tomography were used, using the seistronix RAS 24 seismograph and SAS 4000 ABEM Terameter equipment. These two survey methods were adopted due to the pictorial image they give of the subsurface, enabling a clear view of subsurface structures. A total of five profiles were taken at a total length of 300 m and an inter-profile spacing of 45 m. The results of this survey in correlation with borehole data revealed three distinct layers; overburden, weathered and fresh basement. The overburden consists of the topsoil and lateritic clay, averaging a depth of 3 to 6 m and having a seismic velocity of 100 to 700 m/s and resistivity range of 370 to 750 Ωm. Underneath the overburden is the weathered basement, consisting of brownish fine to medium grained coarse sand, gravel and some disintegrated schistose material, averaging a depth of 6 to 30 m and having a seismic velocity of 700 to 2100 m/s and resistivity range of 56 to 370 Ωm. The depth to the third layer (fresh basement) suggested less compact subsurface of depth >45 m. A close examination of the velocities with depth shows higher velocities at deeper depths (2100 to 3200 m/s) and resistivity > 1500 Ωm.

Keywords: Electrical resistivity, lithology, seismic velocity, test site, tomography.

INTRODUCTION

Geophysical test sites are very important in carrying out training, demonstrations, calibration, and research for many aspects of shallow geophysical surveys. Such sites are found in some parts of the world, such as Leicester University Onatorio; where field test of Scintrex products is carried out. In Nigeria, no such site exists. however, few academic geophysics programs provide field schools because of limited equipment, lack of interpretation software, expense and liability issues.

These constraints mean many students are only briefly exposed to geophysical fieldwork in a show-and-tell type of exercise and many do not have experience with the full workflow of a geophysical survey. This led to the need to establish a geophysical test site in Ahmadu Bello University Zaria, to serve the graduate students of geophysics. An integrated geophysical survey of the area is needed with the aim of characterizing the subsurface structures. Thereafter, different types of objects that respond to all geophysical techniques will be buried at different depths in the site.

Geophysical methods such as seismic, electrical and gravity method for investigating a site is increasingly becoming popular all over the world and has the possibility to give a pictorial image of the subsurface to the geologist and geotechnical engineers (Benson et al., 1984; Goldstein, 2009; Benson and Yuhr, 2002).

In this respect, seismic refraction is the most efficient geophysical tool used increasingly in site investigation (Azwin et al., 2013). It is widely applied in investigating the shallow subsurface conditions in sites such as roads, tunnels, dams, quarries, hydroelectric power plants, subways, nuclear power plants, bridges and many other purposes (Sjogren and Sandberg, 1979; Dutta, 1984; Azwin et al., 2013). Particularly, when in conjunction with the exploratory drill, significant information about the subsurface layers in terms of velocities, thickness and water saturation, as well as elastic properties, can be obtained. Also, geoelectric resistivity imaging has also been used in many studies in site investigation for civil engineering (Aizebeokhai, 2010; Yilmaz, 2011; Coşkun, 2012; Baker et al., 2001). In the resistivity methods, artificially generated electric current are driven into the ground. Any variation in subsurface resistivity (conductivity) alters the current flow patterns which in turns affect the distribution of electric potential. The resulting potential differences established are measured at the surface. Any variations observed from the pattern of potential differences expected from uniform earth are deviations from the uniform earth.

Both the seismic refraction and resistivity survey were carried out to investigate the shallow subsurface condition under the investigated site. This is to give a clear picture of the subsurface structures before a target object that will respond to all geophysical methods and survey is buried in the site.

The literature gives many investigations employing several geophysical methods together, such as seismic, GPR, and ERT (Gaffney et al., 2004; Leucci, 2004; Lascano et al., 2003; Murdie, 2003). Thus, the objectives of this research is to determine both the seismic velocity and apparent resistivity of the subsurface layers, and determine the model subsurface structure.

MATERIALS AND METHODS

Location and geology of the study area

The study area which is part of Ahmadu Bello University farm is situated in Shika, along Zaria-Funtua road, north of Ahmadu Bello University main campus. It lies between latitudes +11^o 12’ 12’’ and +11^o 11’ 28’’ and longitudes +07^o 35’ 42’’ and +07^o 35’ 34’’.

The study area belongs to the Nigeria Basement Complex which according to McCurry (1970), is composed of four distinct rock types. The rocks typically found within the basement complex include gneisses, migmatites, metasediments and some intercalation of amphibolites. The rocks of the basement complex occupy more than 50% of the total land surface of Nigeria. The basement complexes accommodate the metasediments and are made up of gneisses. Exposures are scanty and highly weathered. The rock types are biotite, gneisses, granite gneisses and in parts with subordinate migmatites. The contact between the gneisses and metasediments are gradational, Dahomeyan-Birrimian in age (McCurry, 1970).

The Zaria crystalline rocks are part of the Nigerian Basement Complex. Oyawoye (1964) has shown that there is a structural relationship between this Basement Complex and the rest of the West African basement. This is partly due to the fact that the whole region was involved in a single set of the orogenic episode, the Pan African orogeny, which left an imprint of structural similarity upon the rock units.

Granitic intrusions form a suite of batholiths (the Zaria Batholiths), part of which outcrops as the *Kufena Hill*. The gneisses are found as small belts within the granite intrusions and are also found east and west of the batholiths. The biotite gneiss extends westwards to form a gradational boundary with the schist belt. The gneiss continues eastwards to some extent and is occasionally broken up by the Older Granite (McCurry, 1970). The Older Granite intrusion is supposed to have been formed at the bottom of a fold mountain belt (Wright and McCurry, 1970).

The thrusting imposed on the basement complex during the Pan African Orogeny movement is believed to have brought together rocks of different ages with different structural and metamorphic styles (Grant, 1969). The metasediment probably belongs to the sedimentary and granite facies that were formed in a geosynclinal trough which had earlier developed at the end of the Pan African Orogeny (Tokarski, 1972). During the Pan African Orogeny, the sediments and igneous material, together with the former metamorphosed basement rocks behaved as one tectonic unit. Some of these metamorphosed rocks became assimilated into the granite intrusions that accompanied the last orogeny (Grant, 1969). The study area is completely underlain by the basement rocks which form part of the Paleozoic basement complex of Nigeria (Figure 1).

Electrical resistivity tomography (ERT) measurements

In the ERT method, the distribution of the electrical resistivity of the subsoil is obtained by injecting electrical current (by the current electrodes) into the ground and measuring the potential difference (potential electrodes) at two determined points of the subsurface. The apparent resistivity values depend on the true resistivity distribution. The true distribution in the investigated medium can be estimated by an inversion procedure based on the minimization of a suitable function (Dey and Morrison, 1979).

This function is generally the sum of the squared

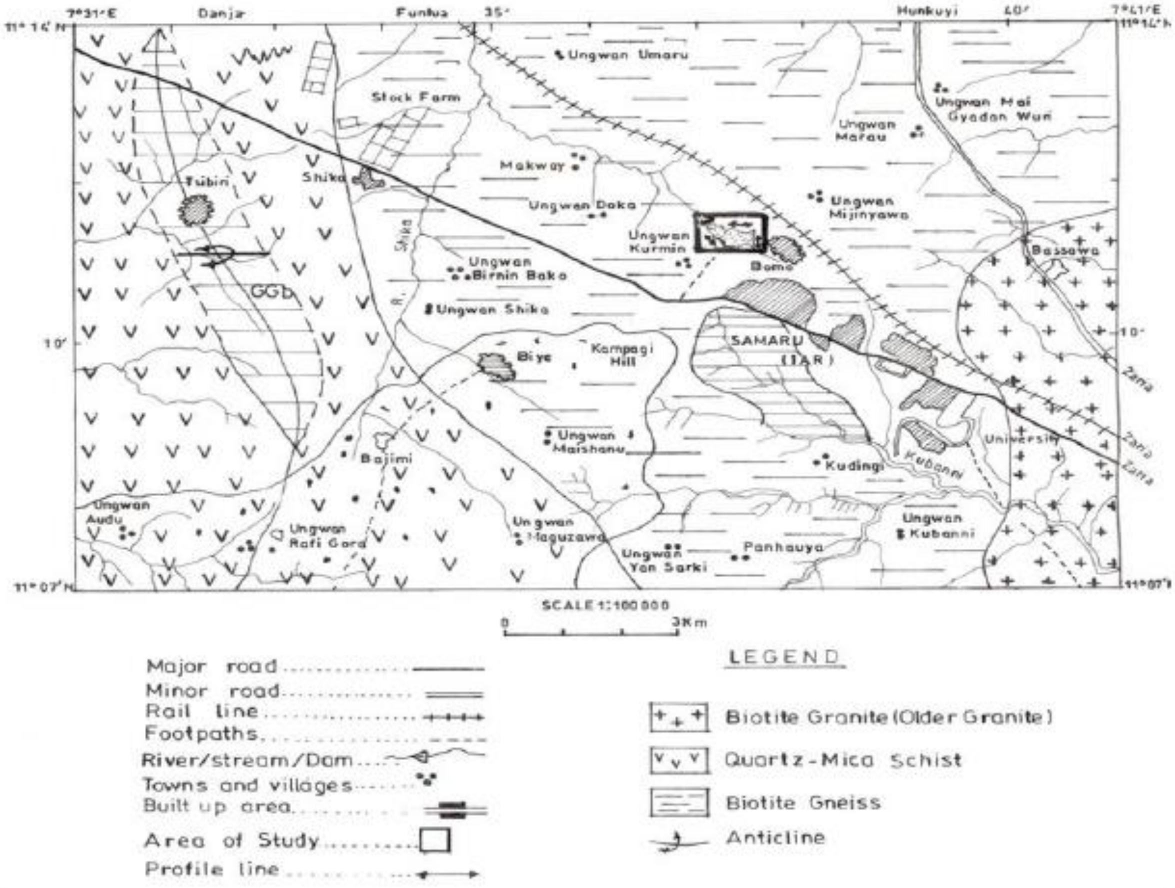

Figure 1. Geological map of Shika and its surrounding showing the Study area (adapted from Ojo et al., 2013).

difference between measured and calculated apparent resistivities. The investigated medium is discretized in a 2D (or 3D) grid of cells, where each cell is assigned an initial resistivity value. A finite-difference (Dey and Morrison, 1979) or finite-element (Silvester and Ferrari, 1990) procedure computes the predicted apparent resistivity at the surface. The solution to the problem, as is well known, is not unique. For the same measured data set, there is a wide range of models that can give rise to the same calculated apparent resistivity values. To narrow down the range of possible models, normally some assumptions are made concerning the nature of the subsurface (i.e. geology of the subsurface, whether the subsurface bodies are expected to have gradational or sharp boundaries) that can be incorporated into the inversion subroutine. The current method of solution minimizes the difference between measured and calculated apparent resistivities using the smoothness-constrained inversion formulation, which constrains the change in the model resistivity values to become smooth (Loke and Barker, 1996; Loke, 2001; Dogan and Papamarinopoulous, 2003). The ‘‘smoothness-constrained robust inversion’’ method (Loke 2001) has proved to be much more useful when the subsurface bodies have sharp boundaries (Loke, 2001).

The ERT measurements were carried out along 5 parallel profiles oriented approximately N-S (Figure 2). The profiles were separated by 10 m inter-profile spacing. Apparent resistivity data were collected using the SAS 4000 terrameter resistivity-meter from ABEM instruments in multi-electrode configuration. The distance between profiles was m and a total of 24 electrodes spaced at 1 m intervals were employed. Data were collected using the dipole-dipole array (Figure 2). The dipole-dipole array was chosen because, as is well known, it is very sensitive to horizontal changes in resistivity, and is, therefore, suitable for mapping vertical structures (Loke, 2001).

Seismic refraction tomography

In the seismic refraction method, the seismic waves, created by artificial sources such as a hammer, propagate through the medium and are refracted at interfaces, where the seismic velocity or density changes. Geophones laid on a single line record the waves returning to the surface

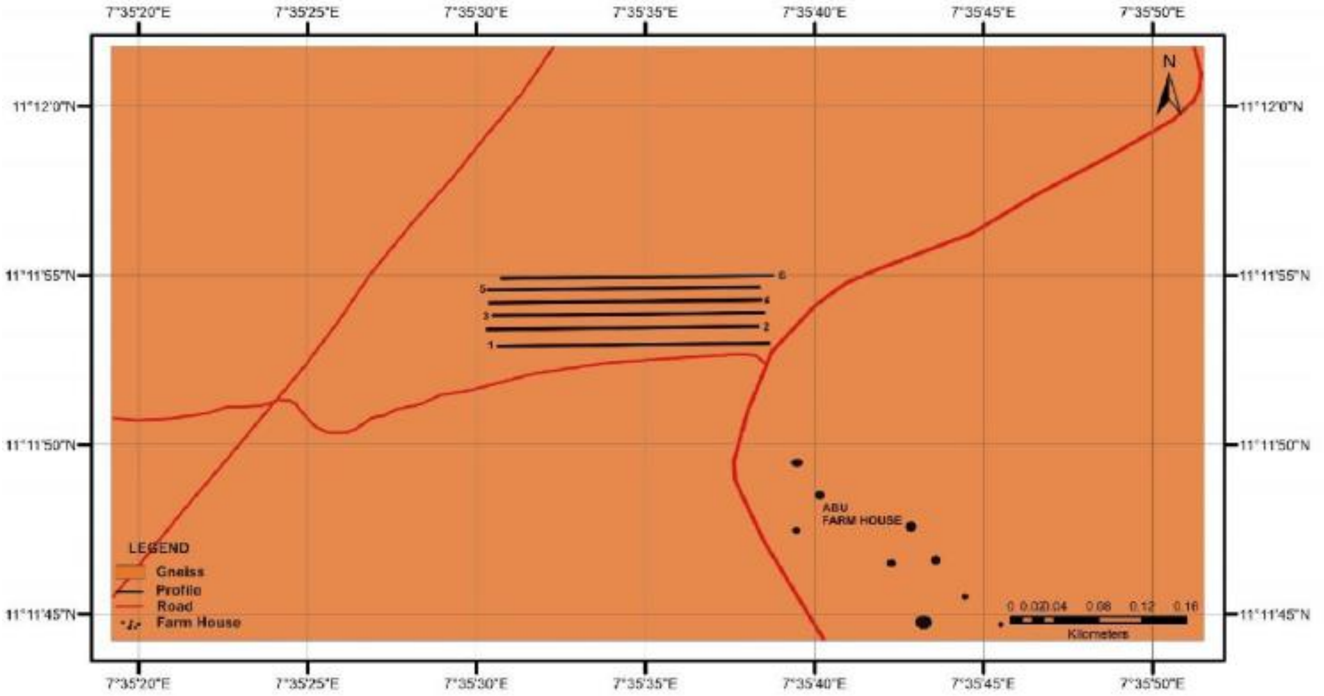

Figure 2. Survey area showing the profile layout.

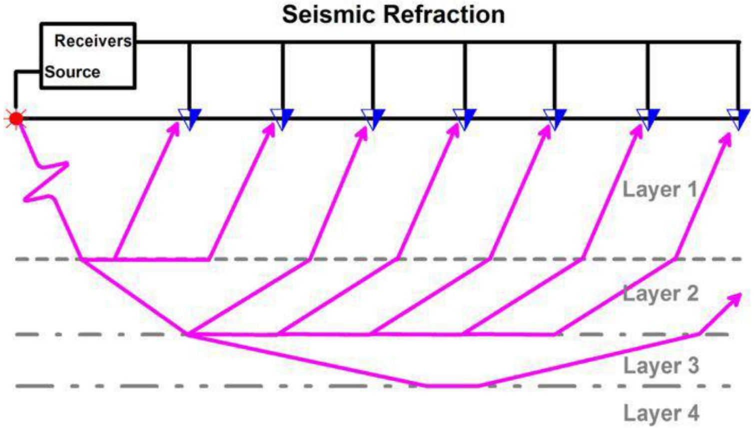

Figure 3. Refraction at multiple horizontal interfaces.

after traveling different distances through the ground. By measuring the travel time between the break and the recording of a seismic signal, the seismic velocity in the subsurface and the depth of the interfaces may be inferred. Conventional analysis of seismic refraction data sets makes simplifying assumptions about the velocity structure that conflict with observed heterogeneity, lateral discontinuities, and gradients (Kilty et al., 1986; Parasnis, 1997). Refraction tomography is designed to resolve velocity gradients and lateral velocity changes, enabling it to be applied in settings where traditional techniques fail.

For a subsurface with multiple acoustic horizontal layers (Figure 3), the principle of reciprocity is valid. Both the forward and reverse travel time curves are of the same nature with the asymmetrical crossing point of the refraction curves about the profile. The arithmetic mean of the apparent velocities obtained from the refraction curves is equal to the true velocity of the refractor. Generally, the travel time equation for a subsurface with many horizontal plane layer interfaces is given by equation 1.

$$t_x = \frac{X}{V_n} + \sum_{i=1}^{n-1} \frac{2h_i\sqrt{V_{i+1}^2 - V_i^2}}{V_{i+1}V_i} \quad \text{-----------1}$$

Where “n” is the number of layers and” i” is the refracting interface number.

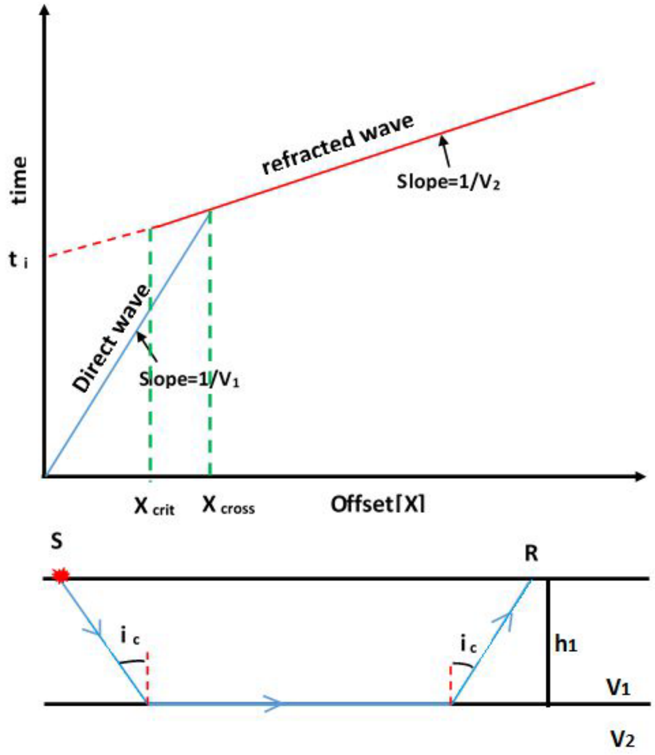

Figure 4. A travel time curve of seismic refraction first arrivals. V_1 and V_2 are velocities of the first and second layers respectively. Note: V_2 is assumed to be greater than V_1.

The time taken for the seismic pulse to arrive at the receivers (geophones) is plotted against the distance of the receivers from the shot location in order to compute the velocities of layers present using the slopes of the T-X curves. The plot of the travel time against the offset distance gives a straight-line graph with three segments as shown in Figure 4.

For interpretation of refraction data five shots were selected on the seismic line: one in the middle, two near shots at the edges of the line, and two on geophones number 4 and 12, respectively. Seismic data was processed using "Seisimager" 2D software. This software employs the intercept time analysis, tomography as well as raytracing for interpretation processing. The very first thing was to download the data from seistronix RAS-24 seismograph by connecting via a local area network cable to the computer. The data were converted into a seisimager format, using the software for the interpretation of the raw data. A value of 5 was set for the "receiver start" in the import data menu, 300 for the "receiver end", 0 for the shot position and input format "SEG2" was chosen. A bandpass frequency of 15 Hz low cutoff and 300Hz high cutoff were applied to take out the low and high-frequency noise. These cutoff frequencies were chosen considering the range of frequencies (5 to 50 Hz) and observing the seismogram. In addition, a manual gain filter was also performed on the band filtered data. The gain function helped in revealing positions of the first arrivals much better (Sandmeier, 2008). Figure 5 to 8 shows the seismic tomography of each profile line.

Seismic data were collected in a rectangular area of 15 m by 12 m, along 2 m spaced parallel profiles oriented approximately N-S, using 24 geophones (14 Hz) at 5 m intervals. A seistronix RAS-24 seismograph instruments were used. The acquisition was achieved using a sledgehammer striking a steel plate as an energy source and a shot-point for each geophone position. Data were stacked at least three times for each source.

RESULTS

ERT data interpretation

The robust inversion scheme was used in order to obtain an image of the true resistivity distribution as a function of depth. The robust inversion method (Loke, 2001) minimizes the absolute changes (l1-norm) in the model resistivity values (Loke, 2001). All dipole-dipole inverted resistivity sections produced low RMS errors (<3%). The Res2dinv software (Loke, 2001) was used to invert all 2D data sets. Figure 9 to 13 gives the inverted section relating to each of the profiles taken.

Considering all profiles, the lithology of the area was

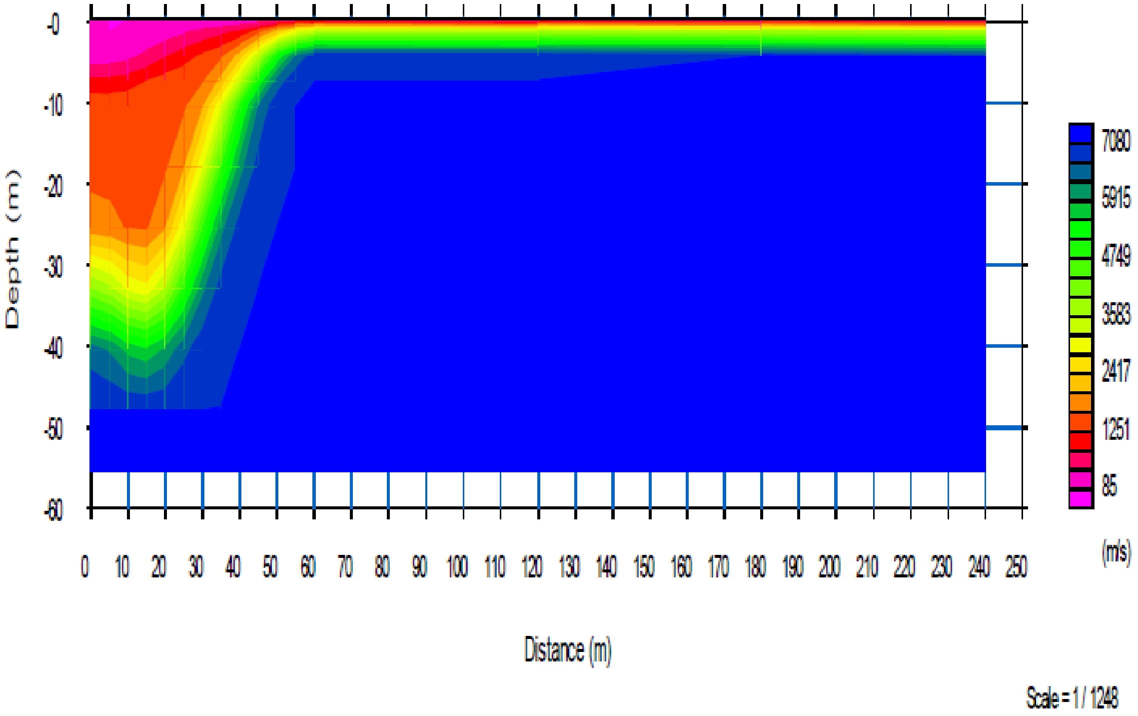

Figure 5. Tomographic section of profile 1.

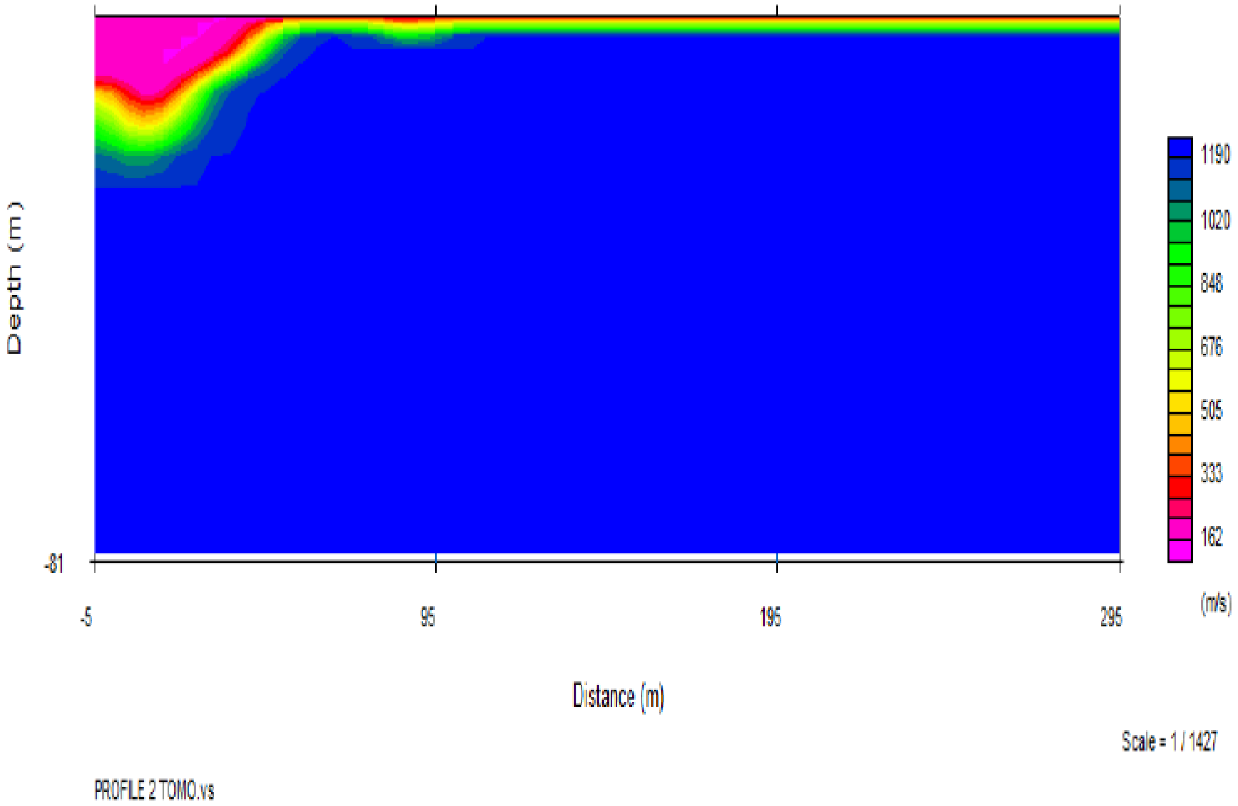

Figure 6. Tomographic section of profile 2.

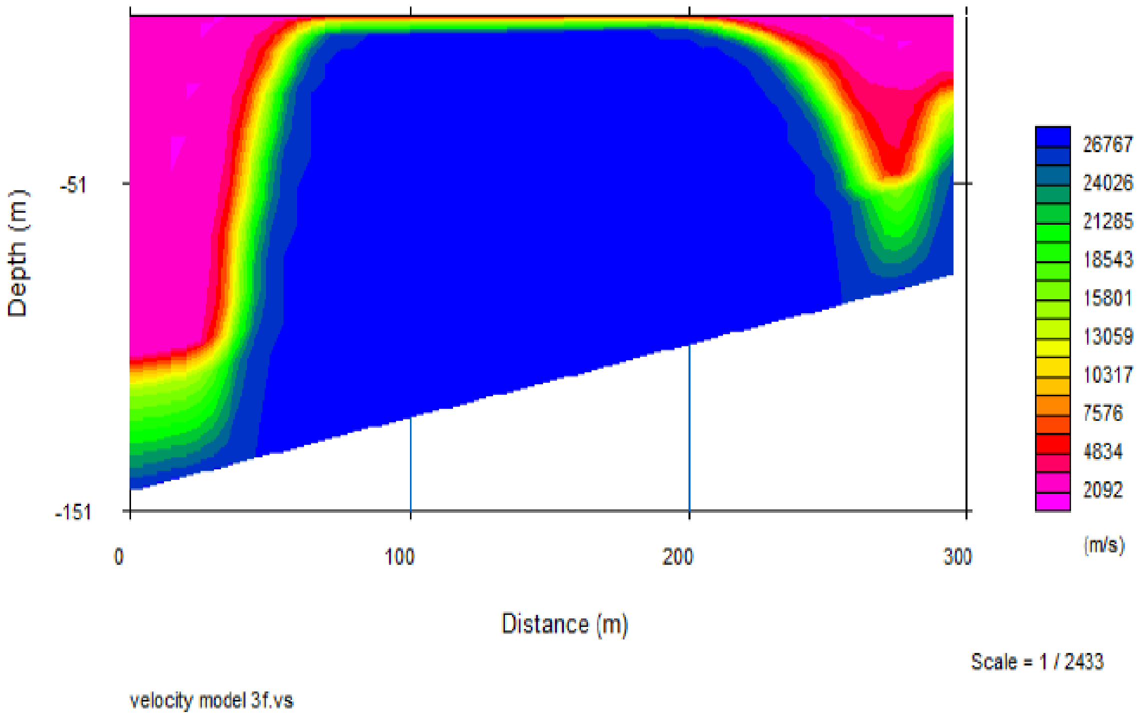

Figure 7. Tomographic section of profile 3.

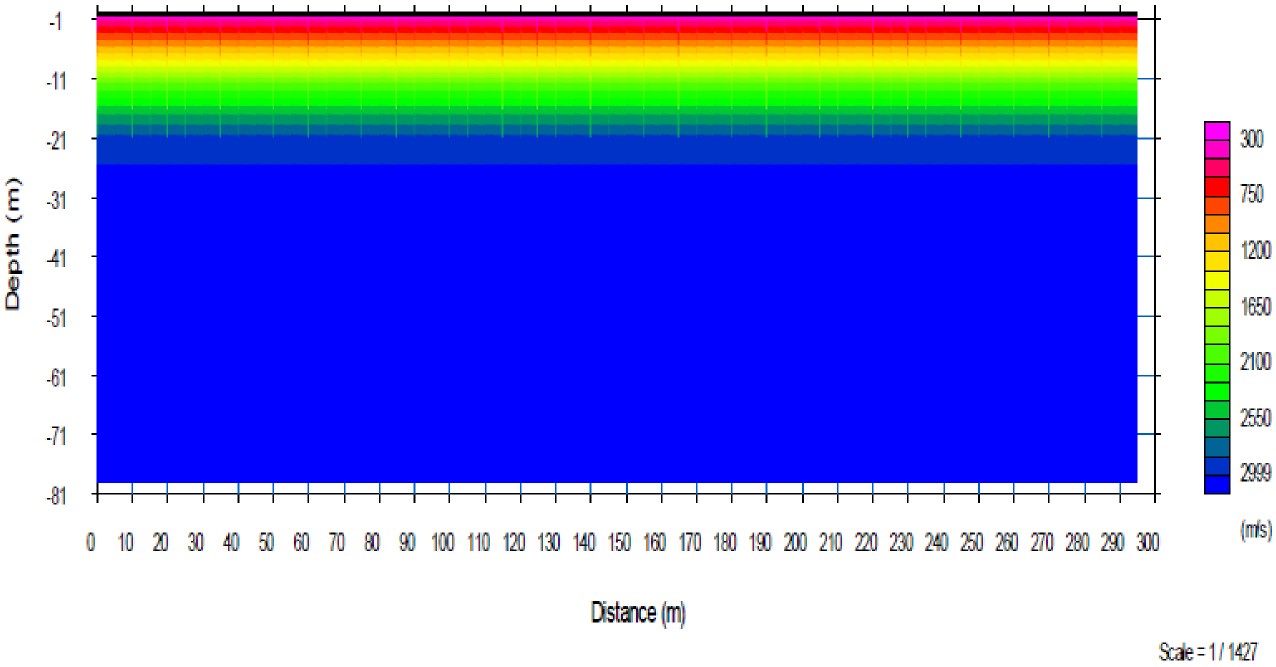

Figure 8. Tomographic section of profile 4.

observed in correlation to a borehole data within the study area. Each profile consists of three distinct layers, the overburden, weathered and fresh basement. The top layer (overburden) is occupied by earth materials interpreted as lateritic soil and clayey sand, with resistivity values ranging from 370 to 750 Ωm with a depth approximately ranging 1 to 6 m. Underneath this layer is the weathered basement, with a depth range of 6 to 23 m. The resistivity of this layer

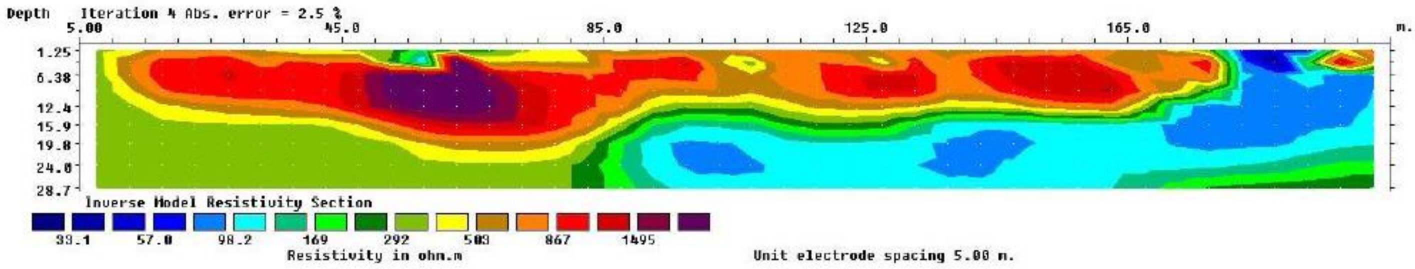

Figure 9. 2D inversion of profile 1.

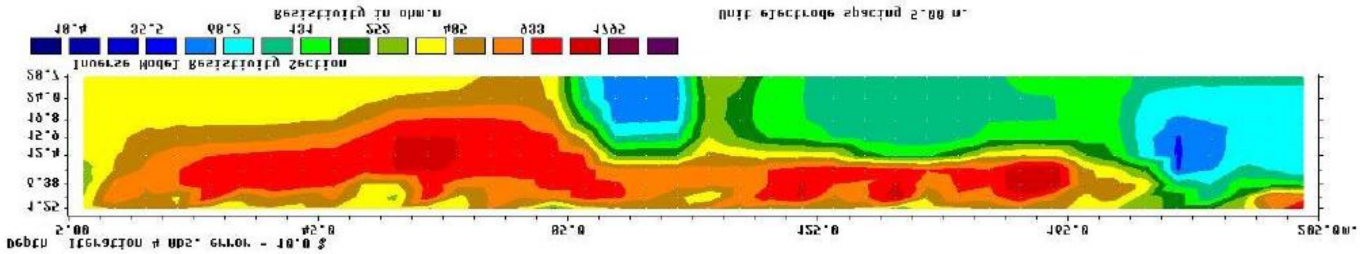

Figure 10. 2D inversion of profile 2.

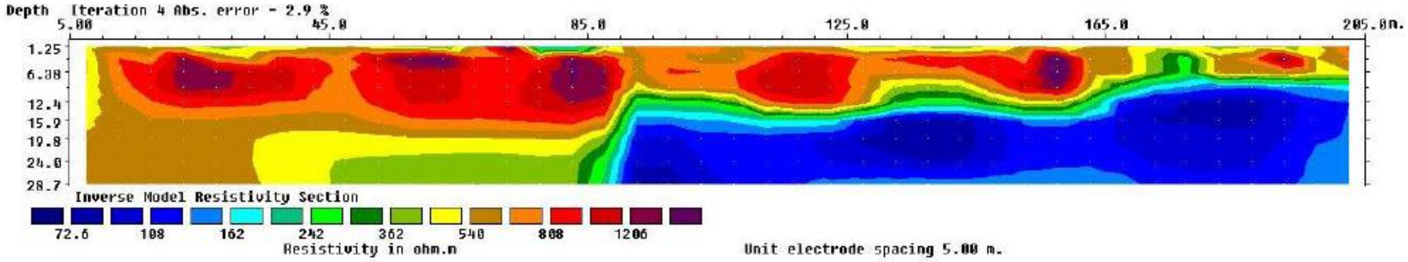

Figure 11. 2D inversion of profile 3.

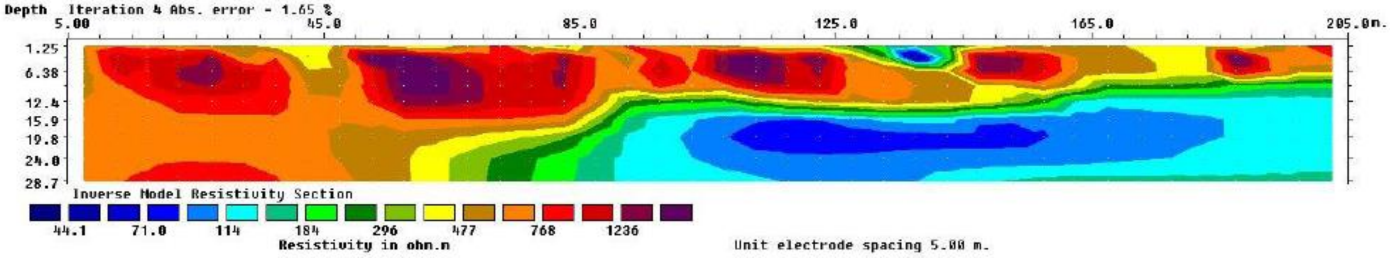

Figure 12. 2D inversion of profile 4.

ranges between 56 to 370 Ωm and can be interpreted as fine brownish gravel and clay materials. The third layer is the fresh basement with depth > 45 m. The resistivity of this layer varies between 970 to 1500 Ωm.

Seismic refraction data interpretation

The results of each profile indicate that the subsurface structure consists of three seismic layers; the first layer is

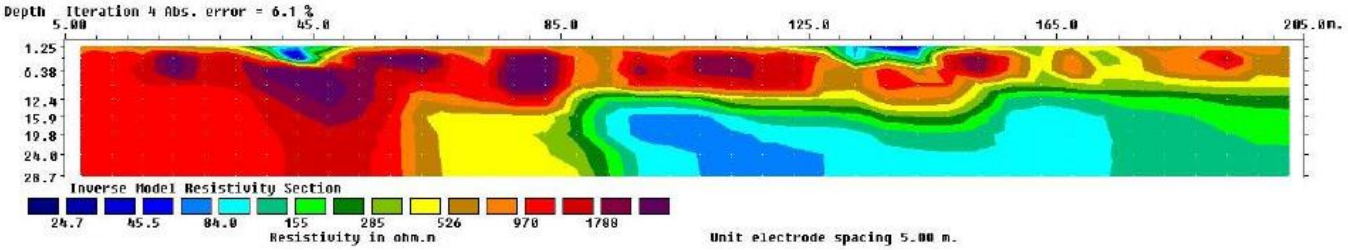

Figure 13. 2D inversion of profile 5.

Table 1. Electrical resistivity and seismic responses of each geological layer.

Lithology	Electrical resistivity (Ωm)	Seismic Velocity (m/s)	Depth (m)
Overburden (top soil)	370-750	100-700	0-6
Weathered basement (clay, gravel and schist)	56-370	700-2100	7-30
Fresh basement	970-1500	2100-3200	>45m

unsaturated overburden with seismic velocity range from 100 to 700 m/s and depth varies from 3 to 6 m. The second layer is a weathered basement with velocity range from 700 to 2100 m/s and a maximum depth of about 30 m. The third layer is the fresh basement with seismic velocity range from 2100 to 3200 m/s and a maximum depth greater than 45 m.

DISCUSSION

In order to map the lithological structures at the proposed geophysical field test site (at Ahmadu Bello University Nigeria), electrical resistivity tomography (ERT) and seismic-refraction tomography methods were used. The results highlighted the reliability of the integrated data interpretation based on two physical parameters with different resolution and sensibility. The integrated interpretation of seismic refraction and resistivity tomography makes it possible to reduce ambiguity. According to Azwin et al. (2013), relatively high resistivity and high-velocity anomalies could be due to more compact material. This was used as guide for infering the different layers in this study.

The field data interpretation showed three geological layers over the entire study area; the top layer, weathered basement layer, and fresh basement layer. The wide range of velocity and resistivity values may be attributed to the heterogeneous nature of the topsoil, due to collective effects of long periods of erosions and weathering suffered by rocks, which has led to some rock exposures. Due to the compact nature and the heterogeneous nature of the weathered layer, it shows abnormally high velocities compared to the velocities of the bedrock in a basement complex.

The seismic and resistivity responses of the top layer along all the profiles are characteristics of topsoil and lateritic clay with a depth of 0 to 6 m for seismic profile 1 (100 m/s and 300 Ωm resistivity), 0 to 6 m for seismic line 2 (300 m/s velocity and 350 Ωm resistivity), 0 to 8 m for seismic line 3 (650 m/s velocity and 400 Ωm resistivity) and 0 to 6 m for seismic line 4 (300 m/s velocity and 400 Ωm resistivity). The velocity and resistivity difference between the profiles suggest that the topsoil for profile 2 and 4 is a little compact than that of profile 1 and 3.

The seismic responses of the weathered layer along seismic profile 1 to 4 are characteristic of clay, gravel, and schist. The variations in the seismic velocity responses of the weathered basement at a depth of 11 to 20 m suggest the heterogeneous nature of the layer. The seismic velocity and apparent resistivity of the weathered basement-recorded along these profiles are composed of consolidated earth materials. The seismic line 1 has a velocity of 1250 to 2000 m/s (100 Ωm resistivities), seismic line 2 has a velocity of 800 to 1150 m/s (200 Ωm resistivities), line 3 has a velocity of 2100 to 3000 m/s (96 Ωm resistivity) and seismic line 4 has a velocity of 1250 to 2000 m/s (150 Ωm). As can be seen, the high velocity in seismic profile 1, 3 and 4 can be attributed to the influence of groundwater. The depth of the third layer (fresh basement) on seismic line 1 and 4, suggest less compact subsurface, a close examination of the velocities with depth shows higher velocities at deeper depths. Table 1 shows the electrical resistivity and seismic responses of each geological layer.

Considering all profiles from both the electrical resistivity tomography and the seismic refraction tomography, it can be seen that no fractures or fault lines cut through the area.

Conclusion

Constructing controlled geophysical test site is one of the most important tasks for educational and research purposes. In the test site, simulation of the real filed objects is essential to enhance the geophysical educational tasks and enrich the results of the geophysical modeling for the shallow geophysical applications in engineering, environmental and archaeological studies. This site has been chosen to simulate most of the subsurface utilities, cavities, different environmental and archaeological materials. This research is important because it is necessary to know the lithology of the area and the possible availability of any anomalous body beneath the subsurface before external targets can be buried that will respond to all geophysical techniques.

Electrical resistivity and seismic refraction tomography give the most detailed picture of subsurface geology because they give the opportunity to view the subsurface layers in two-dimension or three-dimensions. This allows for greater penetration than that captured by other methods

The physical property; p-wave velocity and apparent resistivity, helps in making reliable inferences about the nature and lithology of the subsurface. It is obvious from this research that there are three geological layers over the entire study area. The overburden has two lithologic units' i.e. topsoil and the lateritic clay. The first two layers are resting on a basement structure made up of predominantly weathered basement rock. Generally, the subsurface is made up of clay, sandy clay, fairly weathered granite, and schist, laterite, and dry loose sand. The fresh basement extends beyond a depth of 45 m.

Also, no fault lines or fractured zones were observed in all profiles and as a result, no geological structure was found beneath the subsurface. This further makes the study area a good fit for a geophysical test site because when anomalous targets are buried beneath the subsurface, data being collected will be attributed to their presence and not to geological structures.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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