Applied Journal of Physical Science
Volume 1(1), pages 1-7, February 2019
https://doi.org/10.31248/AJPS2018.012

Article Number: 5E29FD581
http://www.integrityresjournals.org/journal/AJPS

Full Length Research

Geophysical investigation of the seismogenic monitoring center, Ile-Ife, Nigeria

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Received 29th November, 2018; Accepted 14th January, 2019

ABSTRACT: 2D electrical resistivity tomography was carried out at Ile-Ife seismographic station, Osun state Nigeria with the aim of investigating the geological structures beneath the station in order to identify areas of anomalous resistivity are related to fractures or fault lines and also determine the lithologies of the subsurface. The survey was carried out with Terrameter SAS 1000 and ES 464 electrode selector equipment. Dipole-dipole configuration at electrode spacing of 2 m was used to acquire the data. The result showed that the station is underlain by three layers; overburden composed of lateritic clay, clayey sand, the weathered and fresh basement. Fault lines and fractured zones were not observed in all profiles. The result was also compared with bedrock quality grades, which further inferred best sites for seismic station based on the lithology of the area.

Keywords. Electrical resistivity tomography, fault lines, lithology, seismic station.

INTRODUCTION

Seismological observatories are houses specifically built to house seismic hardware. The science of seismology depends critically on data collected at hundreds of observatories world-wide. These observatories are operated by several of agencies, staffed by seismologists and technicians whose training and interest vary widely. While in industrialized countries, the observatory personnel normally have easy access to recent technologies, spare-parts, infrastructure, know-how, consultancy and maintenance services, those in developing countries are often required to do a reliable job with very modest means. Recent seismic activities in Nigeria and some parts of the West-African sub-region has shown that the region is most probably seismically unstable, that is, there exist fault lines that pass through the region. Therefore, the need to continuously monitor the crust and the upper mantle for possible prediction of earthquake phenomena informed the establishment of the Center for Geodesy and Geodynamics. Under the Federal Ministry of Science and Technology, this ministry has been saddled with the responsibility of establishing and networking of Nigeria Network Seismographic Stations. Scientists and technicians at the centers have been working round the clock to ensure that the quality of data obtained from these stations is of international standard.

Seismic site selection is not often given the amount of study it requires. The capacity of any new seismic network to detect earthquakes and to record representative event waveforms will be governed by the signal and noise characteristics of its sites, no matter how technologically advanced and expensive the equipment used. If seismic noise at the sites is too high, many of the benefits of modern, high dynamic-range equipment will be lost. If the noise contains excessive spikes or other transients, or if man-made seismic noise is present, high trigger thresholds will be needed and result in poor network detectability. If a station is situated on soft ground, very broadband (VBB) or even broadband (BB) recording can be useless and short-period (SP) signals may be unrepresentative due to local ground effects. If the network layout is inappropriate, the location of seismic events will be inaccurate, systematically biased, or even impossible.

The observance of noise on the seismic data affects the quality for precise earthquake locations. This noises which could be attributed to geological structures beneath the subsurface, could give false interpretation of the subsurface. One may then infer a related map in terms of bedrock quality grades with respect to their suitability for the installation of seismic recording sites.

This research is to ensure that such data are gotten with less noise due to unknown geological structures beneath the subsurface. To ensure that such data are correct, a geophysical investigation using the two-dimensional electrical resistivity tomography is required to be carried out at the station to identify areas of anomalous resistivity that might be related to fractures or fault lines and to also determine the lithology of the subsurface. This to ensure that the data collected are of genuine quality and not just inferred by geological structures.

According to Virdrih (personal communication, 2001), the underground conditions at a seismic station influences both the seismic signal and the noise conditions and thus have a significant bearing on the potential sensitivity of the station. Usually, the higher the acoustic impedance of the bedrock, the smaller the seismic noise and the higher the maximum possible gain of a station. One may then infer a related map in terms of acoustic impedance or bedrock quality grades with respect to their suitability for the installation of seismic recording sites. Table 1 shows a classification of "bedrock quality" grades and this was used as guide to infer the best sites for seismic station location based on the lithology of the area.

Geophysical investigations of the earth involve studying the physical properties of the earth to provide vital information on subsurface material conditions for numerous practical applications (Loke, 1999). These are done by taking measurements at or near the earth's surface that are influenced by the internal distribution of physical properties. Consequently, analysis of these measurements can reveal how the physical properties of the earth's interior vary vertically and laterally that reflect the subsurface geology (Kearey and Brooks, 1988). Two Recent developments in the electrical exploration methods have resulted in a lot of contributions in providing accurate subsurface information. One of the most important is the increasingly widespread use of two dimensional (2D) and three dimensional (3D) resistivity surveys (Griffiths and Barker, 1993; Ritz et al., 1999; Supper, et al., 1999; White et al., 2001; Dahlin, et al., 2002). The 2D surveys are the most practically economic compromise both in achieving accurate results and in limiting the survey cost (Dahlin, 1996).

Thus, the objective of this study is to determine the thickness and depth ranges of subsurface resistivity layers of the seismographic stations and also identify areas of anomalous resistivity in the various resistivity models that might be related to fracture and fault lines.

MATERIALS AND METHOD

Location and geology of the study area

The Ile-Ife seismographic station is situated on the basement complex in the equatorial rain forest of southern part of Nigeria with latitude 07°32' 46.73''N to 07° 32' 49.06''N and longitude 04° 33' 23.20''E to 04° 32' 50.34''E. The main lithologies include amphibolites, migmatite gneisses, granites and pegmatites. Other important rock units are schists, made up of biotite schist, quartzite schist, talc-tremolite schist, and the muscovite schist. The crystalline rocks intruded into these schistose rocks (Rahaman, 1988). The amphibolite and the hornblende gneiss are the mafic and intermediate rocks in southwestern Nigeria. In Ilesha and Ile-Ife areas, these amphibolites occur as low lying outcrops and most are seen in riverbeds while, the hornblende gneiss crops out at Igangan, Aiyetoro and Ifewara, along Ile-Ife road as low lying hills in southwestern Nigeria (Rahaman, 1988). The hornblende gneiss is highly foliated, folded and faulted in places.

The magmatite-gnessic complex which constitutes over 75% of the surface area of the southwestern Nigerian basement complex is said to have evolved through 3 major geotectonic events:

1. Initiation of crust forming process during the Early Proterozoic (2000 Ma) typified by the Ibadan (Southwestern Nigeria) grey gneisses considered by Woakes et al. (1987) to have been derived directly from the mantle.
2. Emplacement of granites in Early Proterozoic (2000 Ma) and
3. The Pan African events (450-750 Ma).

Rahaman and Ocan (1978) on the basis of geological field mapping reported over ten evolutionary events within the basement complex with the emplacement of dolerite dykes as the youngest. On the basis of wide geochemical analyses and interpretation, tectonics studies, field mapping and plumb tectonics, Oyinloye (2011) had suggested a modified sequence of evolutionary events in the Southwestern Nigeria basement complex as detailed in Table 1 (Burke et al., 1976).

The study area is underlain by regional grey gneiss and mica schist, and a sequence of lateritic clay (aquitards), clayey sand/sand, and weathered/fractured bedrock. The clayey sand/sand and weathered/fractured bedrock constitute the main aquifer, located within a bedrock depression that is the catchment area for the region. The relatively low-lying, gently undulating pediments are dissected by several river valleys (Figure 1).

Data acquisition and processing

To achieve a 2D electrical resistivity tomography of the study area, the ABEM SAS 1000 Terameter was used, choosing the dipole-dipole array. The dipole-dipole array is very sensitive to horizontal changes in resistivity, but relatively insensitive to vertical changes in the resistivity (Dahlin and Loke, 1997). Measurements were made along

Table 1. Classification of different types of outcropping geological formations in "quality" categories (Vidrih, 2001). Grade 5 is the best rock for seismic recordings and grade 1 is the worst.

Grade	Type of Sediment/ Rock	S-Wave Velocity
1	Unconsolidated (Alluvial) sediments (clays, sand, mud)	< 100 – 600 m/s
2	Consolidated clastic sediments (sandstone, marls); schist	500 - 2100 m/s
3	Less compact carbonatic rocks (limestone and dolomite) and less compact metamorphic rocks	1800- 3800 m/s
4	Compact metamorphic rocks and carbonatic rocks	2100– 3800 m/s
5	Magmatic rocks (granites, basalts); marble, quartzite	2500- > 4000 m/s

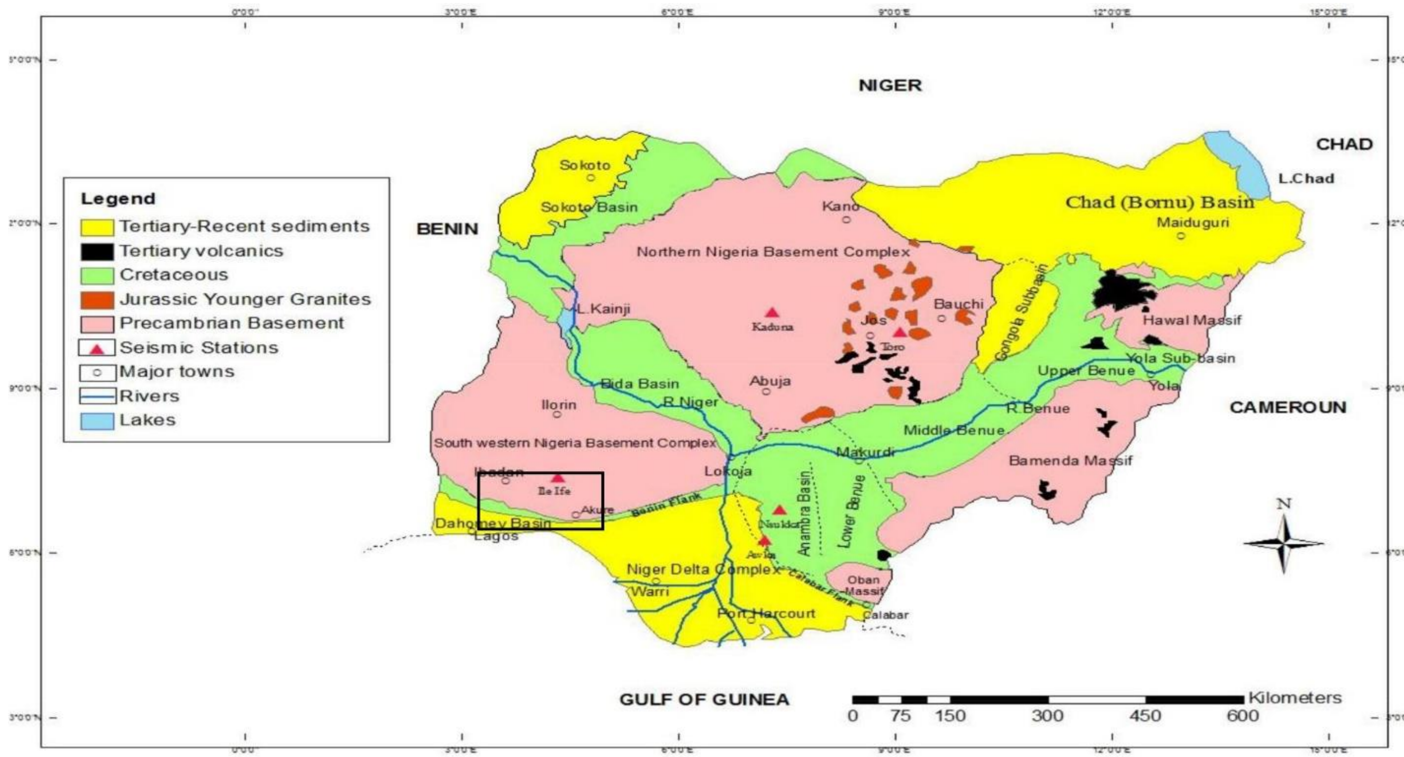

Figure 1. Geological Map of Nigeria showing the Ile-Ife station (Akpan and Yakubu, 2010).

four profiles with each profile covering a total length of 164 m. The choice of direction of the profiles was so as to cover the study area which has a dimension of 164 by 82 m.

The collected data resistivity was processed and inverted using the RES2DINV software developed by Loke and Barker (1996). The inversion technique used was the standard least-square smoothness constrain.

Generally, the programme automatically creates 2D model by dividing the subsurface into rectangular blocks (Loke and Barker, 1996) and the resistivity of the blocks was iteratively adjusted to reduce the difference between the measured and the calculated apparent resistivity values. The apparent resistivity values were calculated by the finite-difference method. The program calculates the apparent resistivity values and compares these to the measured data. During iteration, the modelled resistivity values will be adjusted until the calculated apparent resistivity values of the model agree with the actual measurements. The iteration is stopped when the inversion process converges (i.e., when the RMS error either falls to acceptable limits, usually less than 5% or when the change between RMS errors for consecutive iterations becomes infinitesimally small). Prior to data inversion, the apparent resistivity data set were inspected in accordance with the suggestion of Loke (2002) for bad datum point and such points were deleted.

Boreholes are often used to correlate results obtained from geophysical surveys as these surveys are indirect. This is often done by correlating apparent resistivity obtained in an area with the lithological information in the area. Boreholes which provide lithologic information, are necessary and reliable source of primary data and Electrical Resistivity Imaging (ERT) interpretations provide secondary information. The 2D inversion results of the

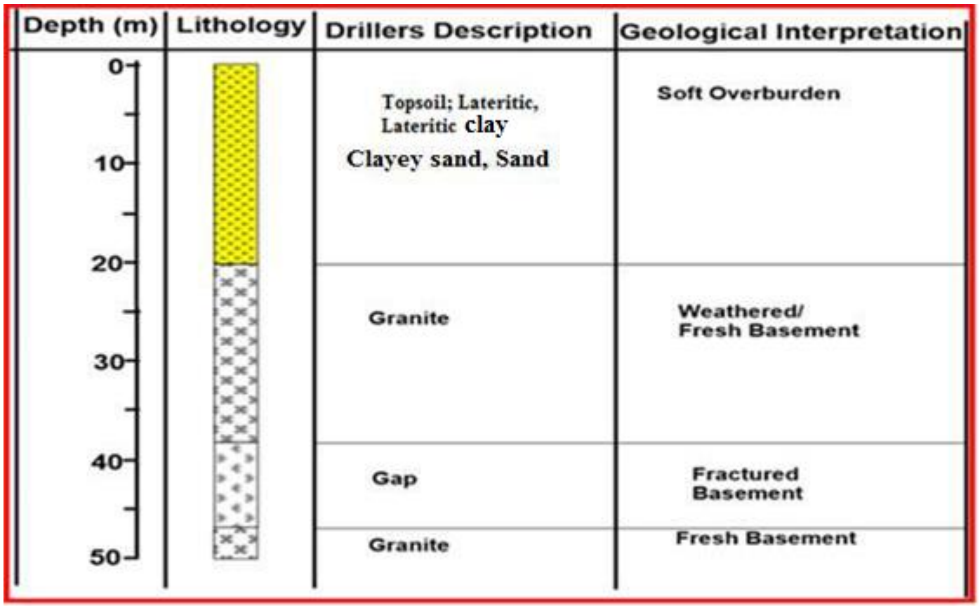

Figure 2. Lithological units for borehole log of the study area.

Table 2. Range of resistivity values and their Corresponding geologic interpretation derived for this study.

Common Rocks/ Materials	Resistivity (Ohm Meters)
Clay	1-500
Graphic Schist	10-500
Top Soil	50-100
Gravel	100 – 600
Weathered Bedrock	100-1000
Gabbro	100-500,000
Sandstone	200 - 8,000
Granite	200 - 100,000
Basalt	200 - 100,000
Limestone	500 - 10,000

survey were correlated with Borehole log taken within the study area (Figure 2). Table 2 gives the standard resistivity values that was used to infer the range of resistivity values encountered in the inversion model of all the profiles.

RESULTS

The results of the standard constrain inversion technique for the dipole-dipole array configuration for each profile is presented in Figures 3 to 6. R.M.S. errors of 2.5, 2.3, 2.8 and 3.6% were obtained. The top layer is composed of sand and laterite with resistivity values ranging between 194 Ωm to 400 Ωm having thicknesses ranging from about 1 to 3 m from the surface, this layer extends along the profile from 5 m to almost 80 m. The second layer is composed of wet clayey sand/sand, with resistivity values ranging from 500 to 600 Ωm. The third layer which was encountered at depth ranging from 5 to 12 m, consist of highly weathered/fractured basement with resistivity values ranging from 500 to 1200 Ωm. The fourth layer consist of fresh bedrock that consists of mica schist to grey gneiss at a depth greater than 12 m, with resistivity values of 500 Ωm (Figure 3).

Profile 2 runs north-south of the study area, covering a distance of 82 m. The top layer of this profile is occupied by earth materials interpreted as lateritic soil, with resistivity values ranging between 370 to 750Ωm having thicknesses ranging from about 0 to 3 m from the surface, this layer extends along the profile from 13 m to almost 180 m. These regions are to be consolidated laterite, having high resistivity values greater than 800 Ωm. Underneath this layer is a weathered basement rock which is highly fractured and exists with a depth of about 4 m beneath 55

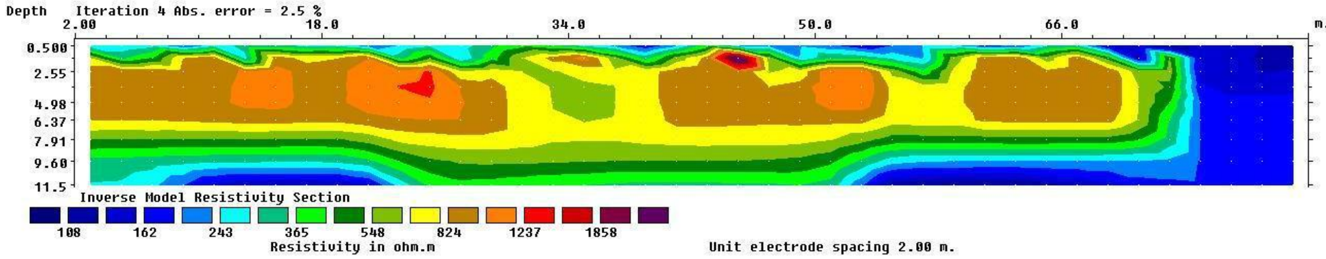

Figure 3. 2D inversion of the dipole-dipole array data along profile 1.

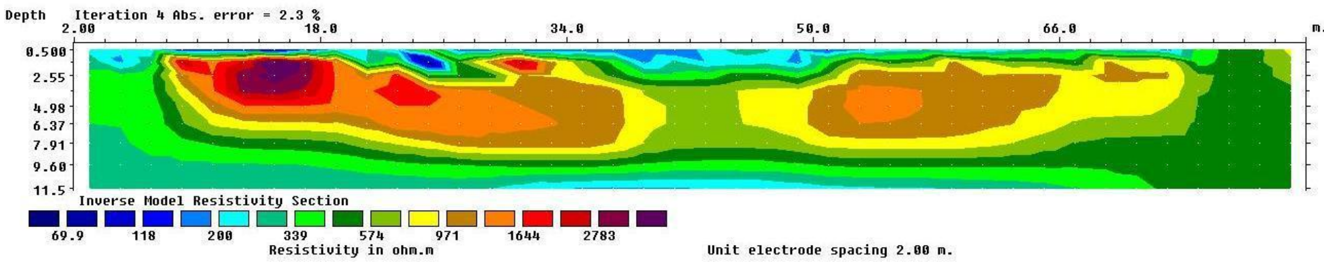

Figure 4. 2D inversion of the dipole-dipole array data along profile 2.

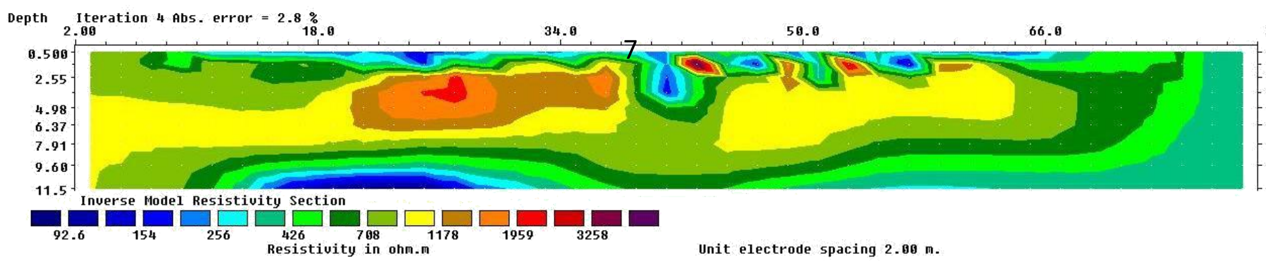

Figure 5. 2D inversion of the dipole-dipole array data along profile 3.

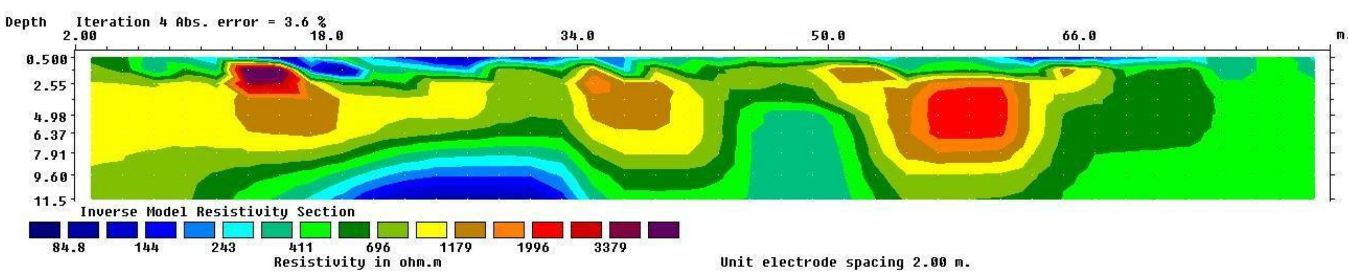

Figure 6. 2D inversion of the dipole-dipole array data along profile 4.

m mark along the profile, with variable thicknesses to the depth of about 7 m. The resistivity of this layer ranges between 56 to 370 Ωm and can be interpreted as fine brownish gravels to medium sand and clay material (Figure 4).

Profile 3 runs north-south of the study area, at an inter-profile spacing of 20 m from profile 2. The resistivity model showed low resistivity values (200 to 285 Ωm) at a depth of about 0 to 2.5 m, with a lateral distance of 5 to 68 m. Higher resistivity values (1000 to 2000 Ωm) are found at a depth range of about 3.0 to 7.90 m, covering a lateral distance of 5 to 60 m. Lower resistivity range (200 to 250 Ωm) is observed at depth of about 8.0 to 11.5 m, with a lateral distance of 20 to 55 m (Figure 5).

Profile 4 runs west-east of the study area, with an inter-profile spacing of 20 m from profile 1. Low resistivity values (100 to 300 Ωm) were observed at a depth range of about 0 to 2.55 m, with a lateral distance of 5 to 70 m. Higher resistivity values (1000 to 2500 Ωm) were observed at a depth range of 3.0 to 7.90 m, covering a lateral distance of 5 to 65 m. Lower resistivity range (130 to 230 Ωm) was observed at a depth of about 8.0 to 11.5 m, covering a lateral distance of 20 to 55 m (Figure 6).

DISCUSSION

Electrical resistivity tomography has shown the lithology of the study area as associated with the resistivity of each layer. These results correlate with the borehole log of the area and standard resistivity values, which were used as control. The investigation reveals that the lithology logs of the study area comprises of four major geologic layers. The top layer composed of dry sand and laterite; the second layer composed of wet clayey sand/sand; the third layer, which was encountered in all profiles consists of highly weathered/fractured basement; and the fourth layer consists of fresh bedrock that consists of mica schist to gray gneiss. According to Olorunfemi et al. (2015) and Faleye and Olorunfemi (2015), the Ile-Ife sedimentary basin are composed of different lithologic sequence. These includes the topsoil, lateritic clay, weathered basement and fresh bedrock. This geologic sequence conforms to that obtained in this research. But a further knowledge of the bedrock quality grade was done to show and infer the best geological formation fit for seismic recordings.

As compared with Vidrih (2001) result on the “bedrock quality” grade on geological formations best suited for seismic recordings, the lithology of Ile-Ife seismic station falls in the grade 5, indicating it’s a good fit for seismic recordings. Good contact between seismic sensors and bedrock is a basic requirement. Soil and/or weathered rock layers between the sensor and the bedrock will modify seismic amplitudes and waveforms. As such, from each profile, it was seen that the level of weathering of layers minimal as no fracture zones were found.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

Conclusion

2D electrical resistivity tomography has provided a clear view of the lithological units and geo-electrical structure underlying the study area. The area is underlain by four layers of different lithological units. Also, no fault lines or fractured zones were observed in all profiles and as a result no geological structure was found to infer false results to the seismic station. This research is to create a standard guide and template towards factors to be considered before a seismic station is sited, as this will enhance the quality of data gotten from such stations. This is of importance because of the recent seismic activities in Nigeria and some parts of the West-African sub-region which has shown that the region is most probably seismically unstable, that is, there exist fault lines that pass through the region.

However, other geophysical methods and factors could be employed to further show the structures beneath the subsurface.

ACKNOWLEDGEMENT

The authors wish to thank the Center for Geodesy and Geodynamics, Toro for their technical aid and support. Many thanks are due to Prof. Kola Lawal, Department of Physics, Ahmadu Bello University Zaria, for his technical aid, advice and interest.

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