Geophysical Investigation of the Origin of Abrupt Changes in Subsurface Properties in Zaria Area, Nigeria.

I.B. Osazuwa, Ph.D. [1*]**; S.O. Ibe, Ph.D.** [2]**; and G.N. Egwuonwu, Ph.D.** [3]

[1]Ahmadu Bello University, Zaria, Nigeria.
[2]Federal College of Education, Zaria, Nigeria.
[3]Federal College of Chemical and Leather Technology, Zaria, Nigeria.

E-mail: iosazuwa@yahoo.com*
stphnibe@yahoo.com
gabneche@yahoo.com

ABSTRACT

The causes of some arbitrary and sharp changes, within a short lateral distance, of some physical properties of the subsurface in Zaria area were investigated in this work. The research area is located within the Kubanni Valley which is characterized by a high concentration of valley networks. The study was carried out in the vicinity of a valley in the study area. 2D seismic refraction tomography data were collected along four profiles approximately perpendicular to the strike of the valley and two profiles, each on the flanks of the valley, using ABEM Terraloc MK6 Seismograph with 24 channels. The data collected were tomographically inverted. The results suggest that the basement in the area is characterized by fracture zones which are identified on the tomograms as low p-wave velocity zones flanked by high p-wave velocity zones. The results also suggest that the p-wave velocity range of about 5120 ms^{-1} – 9093 ms^{-1} of part of the basement rock on one side of the valley differs significantly from the range of about 2550 ms^{-1} – 5831 ms^{-1} on the other side. This sharp difference in the p-wave velocity ranges suggests sharp differences in the physical properties of part of the basement rocks on either side of the valley. It also suggests contacts of different rock blocks in the area. This result prompted further investigation using resistivity tomography. The average basement resistivity of about 2500 Ωm in the western part of the valley and about 12500 Ωm in the eastern part further suggests contacts of different rock blocks in the area. It was concluded that contacts between different rock blocks and high concentration of fracture and fault zones are most probably responsible for the arbitrary and sharp changes of some physical properties of the subsurface in the study area.

(Keywords: Zaria Batholiths, Nigerian Basement Complex, rock contacts, tomography inversion, downthrow, grabenation)

INTRODUCTION

The Zaria Batholiths is part of the basement rock in the Nigerian Basement Complex. It is located in the Zaria area of northwestern Nigeria and approximately lies between longitude 7° 00′ and 8° 00′ E and latitude 10° 00′ and 12° 00′ N. The area has been the subject of considerable study since the early 1970s owing to some arbitrary and sharp changes, within a short lateral distance, of some physical properties of the subsurface measured. Some of the physical properties of the subsurface measured or calculated which have shown arbitrary and sharp changes within a short lateral distance in the area are resistivities, p-wave velocities and densities.

Over the years, some researchers have tried to identify and investigate the basement structures and their depths within the area which are responsible for these diverse physical properties of the subsurface, using geological and geophysical methods. These investigations include those of McCurry (1970), Webb (1972), Adeniyi (1987), Ike (1988), Shemang (1990), Osazuwa et al. (1992) and Olatinwo (1994). Their results had shown that the depth to the basement in Zaria Area ranges between 0 m and 65 m. However, none of these investigators used imaging techniques in the study. Hence, this study is an attempt to use geophysical imaging technique, which is less ambiguous in interpretation, in the investigation of the subsurface in part of the Zaria Batholithic environment. This study is primarily aimed at delineating the structures that are responsible for these diverse physical properties of the subsurface in the area.

THE STUDY AREA AND ITS GEOLOGY

The part of the Zaria area covered by this study lies between latitude 11° 08′ 30.0″ N and 11° 09′ 09.8″ N and longitude 7° 39′ 41.9″ E and 7° 39′ 42.6″ E (Figure 1(a)). It is located within the place known as Kubanni valley (Figure 1(b)) which is characterized by high concentration of valley networks. The study was carried out in the vicinity of a valley in the study area which is about 1.0 km long (Figure 1 (a)) and has an average width of about 15.0 m.

According to Hore (1970), Zaria is located on a plateau at a height of about 0.67 km above the mean sea level and more than 643.71 km away from the sea and possesses a tropical Savanna climate with distinct wet and dry seasons. The area belongs to the Precambrian basement complex of northern Nigeria. It is composed of three rock types which include the basement gneiss, porphyritic granite and medium grained granite. The porphyritic granite and medium grained granite were intruded into the basement gneiss during the Pan African (Garba and Schoeneich, 2001). The greater part of the area is covered with thick regolith mainly derived from in-situ weathering of the basement rocks.

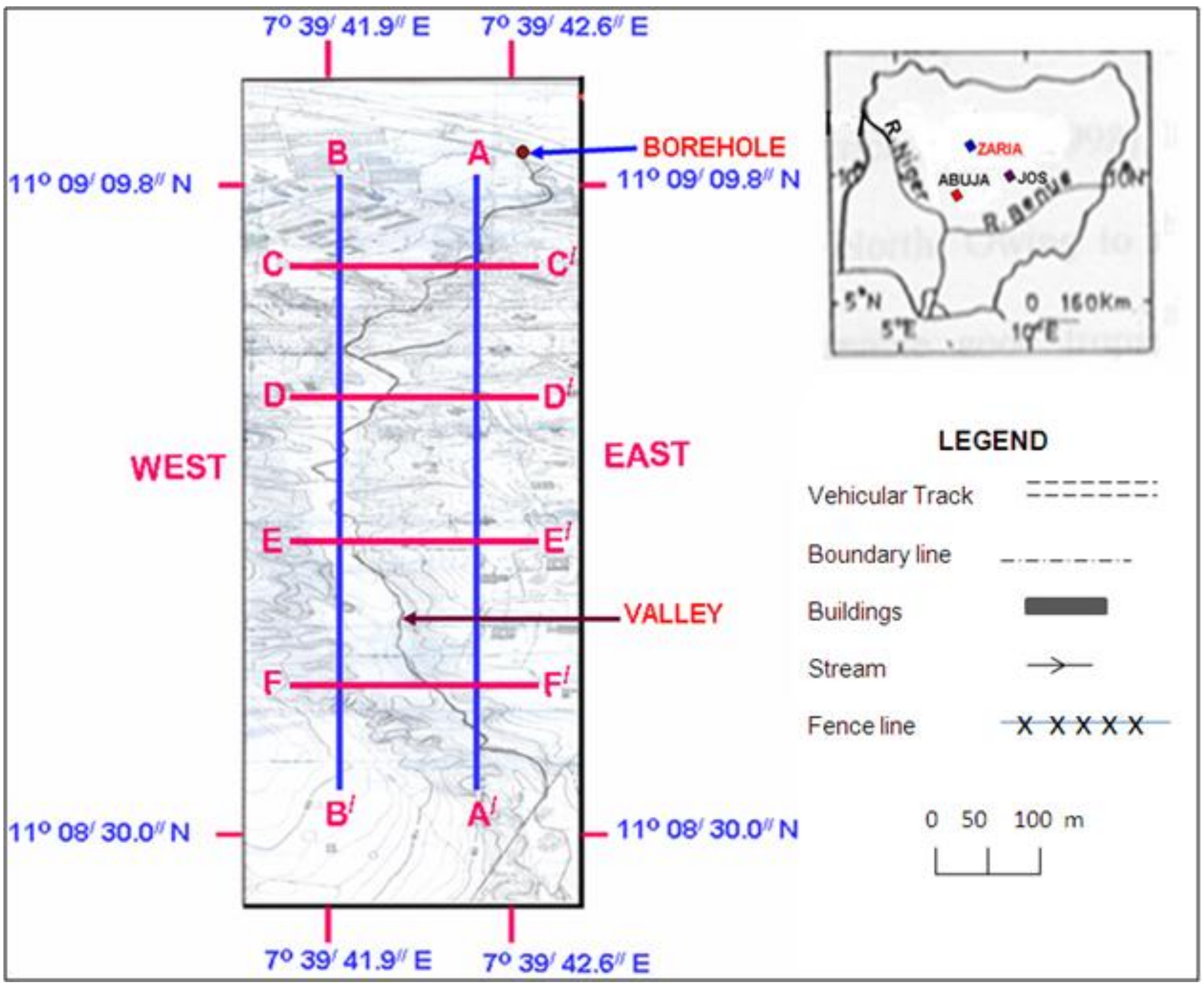

Figure 1a: The Map of the Study Area Showing the Profiles Where the Data Were Collected.

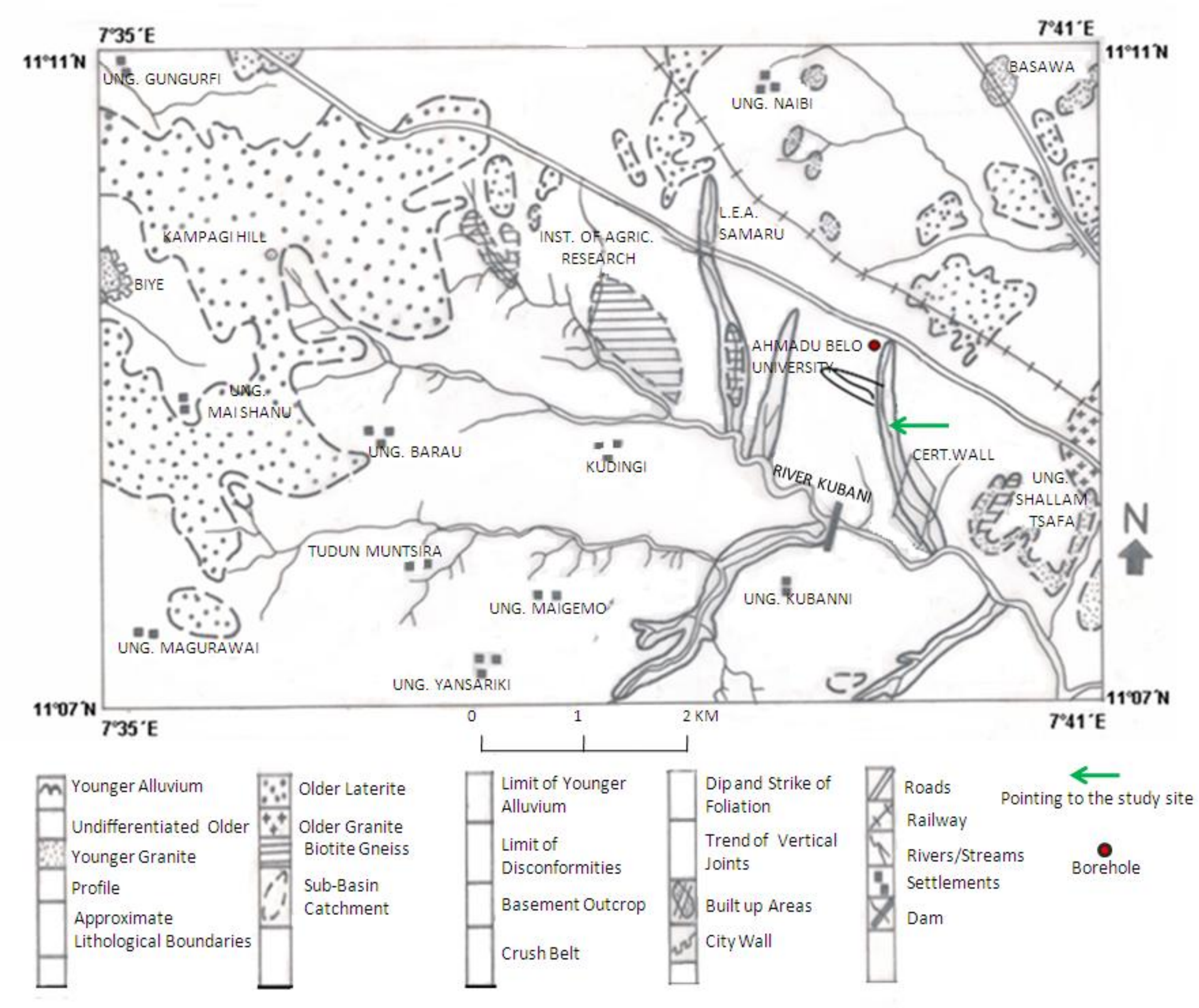

Figure 1b: The Geology Map of the Study Area Showing the Location of the Study Site.

GEOPHYSICAL METHOD USED FOR THE STUDY AND ITS BASIC THEORY

The geophysical method used for this study is seismic refraction and the technique is refraction tomography. Assuming a multiple layer earth, for simplicity, and critically refracted ray paths, the travel time t is related to the depth Z of the refractor by:

$$t = \frac{X}{V_n} + \sum_{j-1}^{n-1} \frac{2 Z \, Cos \, i_j}{V_j}$$

Where X = the distance between the shot and geophone,

i = the angle of incidence when the wave strikes the refractor = the angle of refraction when the ray re-enters the first medium,

V_j = the velocity of the wave in the first layer

V_n = the velocity of the wave in the nth layer and j denotes the layer.

Tomography is an inversion program where measurements are made of energy that has propagated through a medium and the character of the energy received is then used to infer the properties of the medium through which it propagates. According to Lo and Inderwiesen (2000) tomography is an imaging technique which generates a cross-sectional picture (a tomogram) of an object by utilizing the object's response to the non destructive, probing energy of an external source. In this research work, seismic ray tomography, which is a form of traveltime inversion used to determine lithologic velocity was used.

DATA COLLECTION

The seismic tomography data were collected along six profiles shown in Figure 1 (a) using ABEM Terraloc MK6 Seismograph with 24 channels (ABEM Instrument AB, 1994). The profiles are AA/, BB/, CC/, DD/, EE/, and FF/. Profiles AA/ and BB/ are respectively on the flanks of the valley, parallel to its strike. Profiles CC/, DD/, EE/, and FF/ are almost equally distributed across the entire length of the valley, perpendicular to its strike. Data collection along the profiles parallel to the strike of the valley involved roll-along and the electrode spacing along all the profiles is 5.0 m.

DATA PROCESSING AND RESULTS

The data collected from the field were subjected to different stages of processing using "REFLEXW" software (Sandmeier, 1998) to enhance signal to noise ratio. The raw data were converted to "Reflex" format which the "REFLEXW" software recognizes and uses for the interpretation of the raw data. The first arrivals were picked from the filtered data. Figure 2 illustrates the picked first arrivals in one of the processed data for a single shot.

All the picks for each spread were loaded to obtain the travel times for that spread (Figure 3) and the travel times for that spread were assigned to layers. Figure 4 illustrates the assignment of travel times to layers for a spread.

Models were generated after the wavefront-inversion of the layers. The topography values along the profile where the data were collected were applied on the models to update the depths to the subsurface structures beneath the profile. The inversion for the first layer only consists of the determination of the velocities. Figure 5 shows the models generated for a processed data for one of the spreads along a profile. The model generated and the travel time data were used for the tomographic inversion of the seismic refraction data.

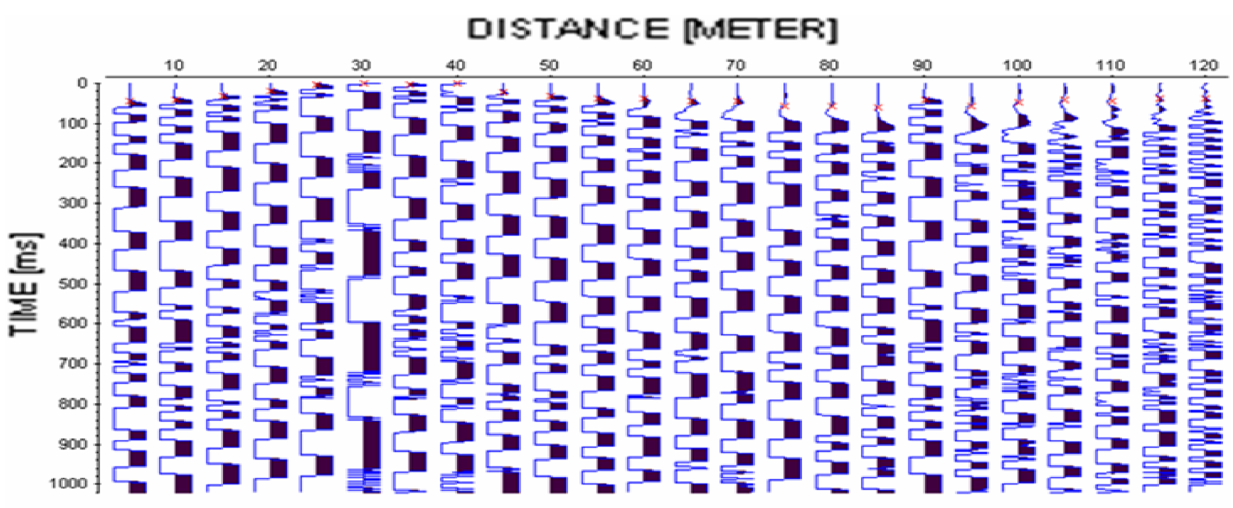

Figure 2: Illustration of Picked First Arrivals (red crosses) for a Single Shot.

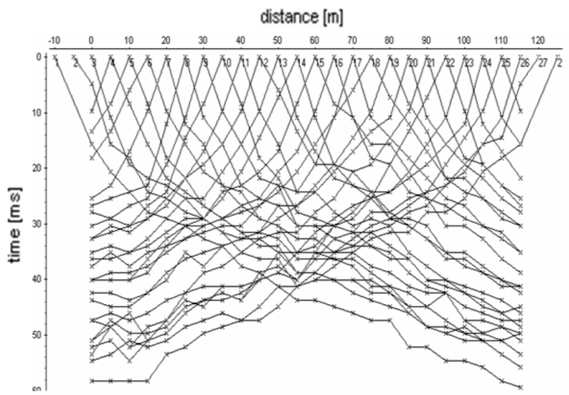

Figure 3: Loaded Travel Time for one Spread along a Profile.

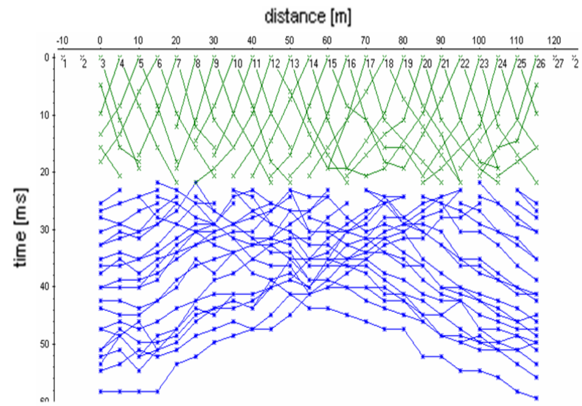

Figure 4: Assignment of Layers to Travel Times.

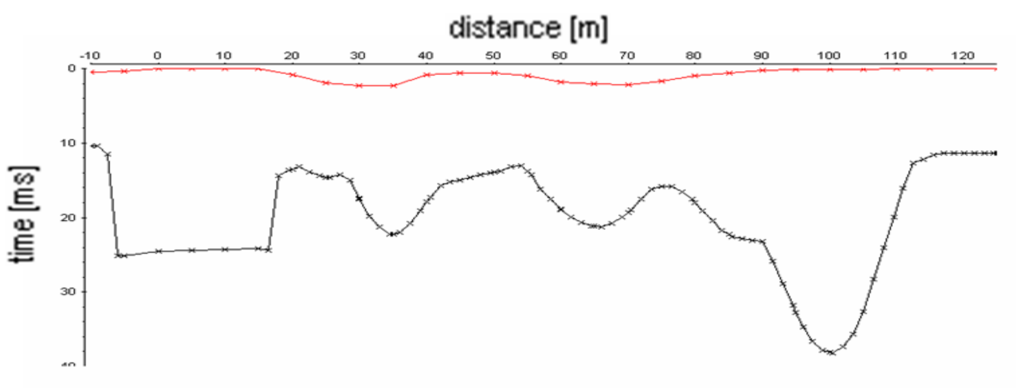

Figure 5: Models Generated for a Processed Data for a Spread along a Profile.

Figures 6 and 7 show the tomograms for the profiles parallel to the valley's strike while Figures 8, 9, 10, and 11 show the tomograms for the profiles perpendicular to the valley's strike. The interpretation made for each tomogram is placed by its side. A log of the nearest borehole to the valley (determined in 2005 by Hydro – Skills and Engineering Services Limited, Kaduna, Nigeria) which is located at approximately latitude 11^{o} $09^{/}$ $11.0^{//}$ N and longitude 7^{o} $39^{/}$ $43.0^{//}$ E or about 70 m in the north–west of the valley (Figure 1a) aided the interpretation. Also, the geology of Zaria Area aided the interpretation.

The results suggest that the average minimum depth to the basement in the area is about 28.5 m. The results also suggest that there are weak zones in the subsurface, within the basement, in the study area. These weak zones are identified on the tomographic pseodosections as low velocity zones flanked by high velocity zones. The weak zones are most prominent on the tomography sections of the profiles that are perpendicular to the strikes of the valleys. The results also suggest that the physical properties of part of the basement rock in the eastern part of the valley (Figure 6) differ significantly from the physical properties of the basement rock in the western part (Figure 7).

The evidence of significant differences in physical properties of the basement rocks underlying either side of the valley is seen on the sharp differences on the p–wave velocities of the basement rocks on either side (Figures 6 and 7). This result prompted confirmation using a tomography technique which is more sensitive in delineating rock units than seismic tomography.

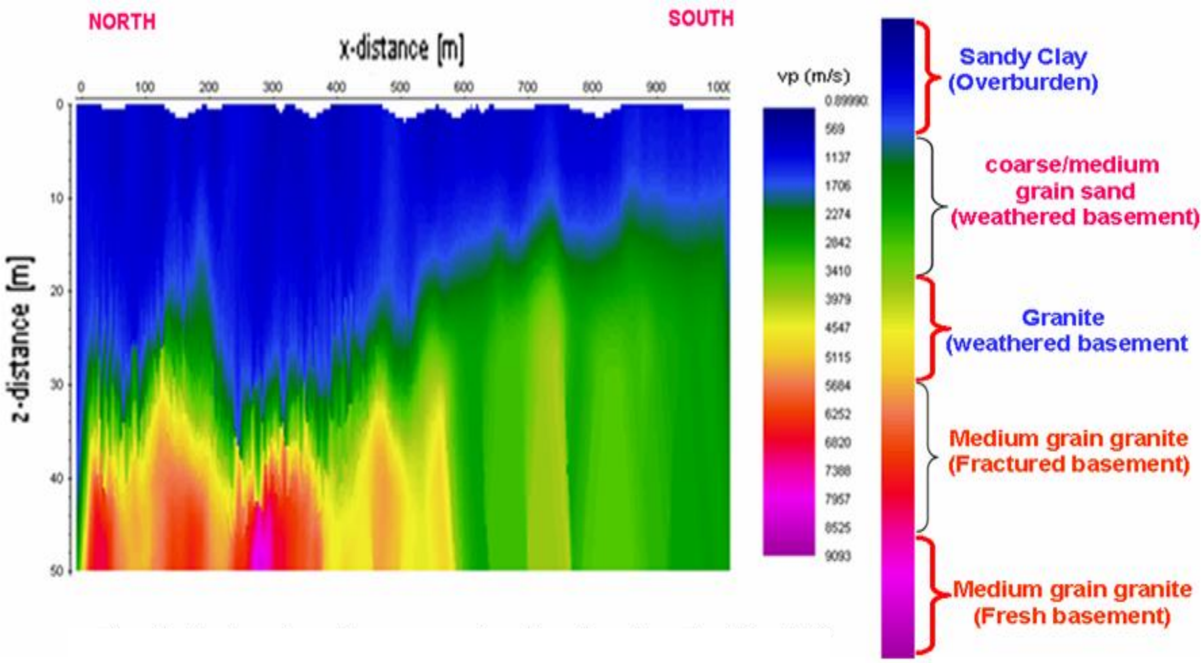

Figure 6: Refraction Tomography Section for Profile AA/

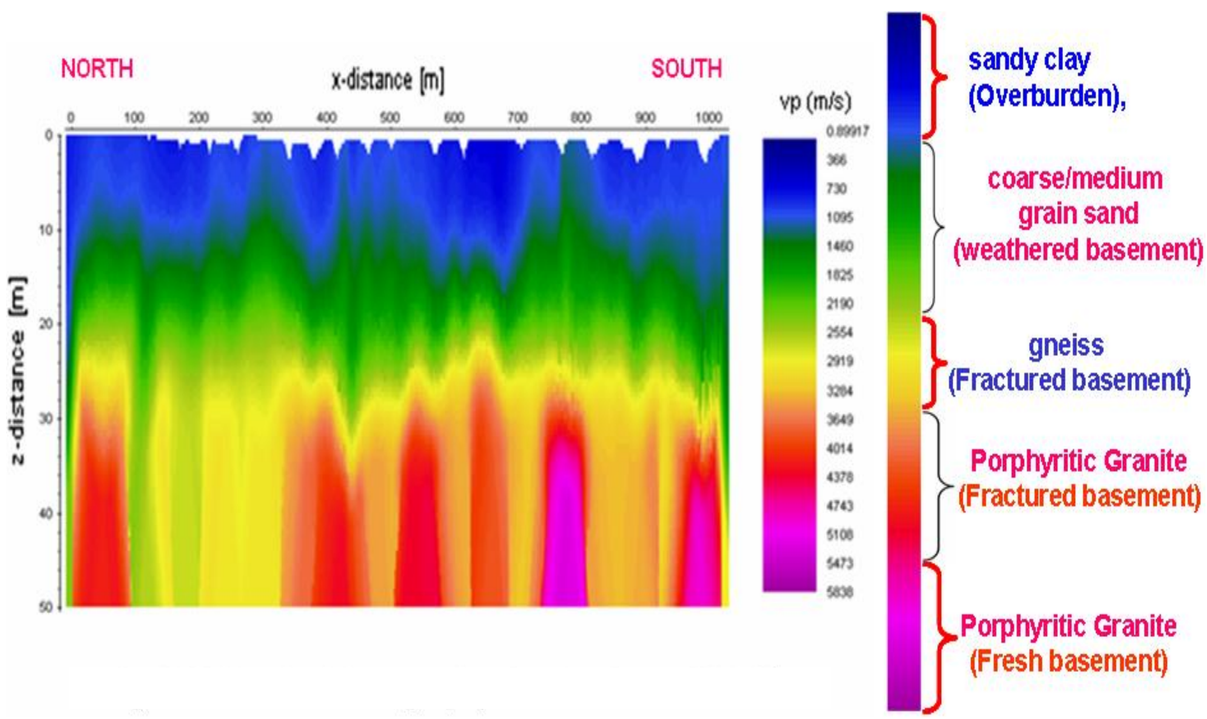

Figure 7: Refraction Tomography Section for Profile BB/

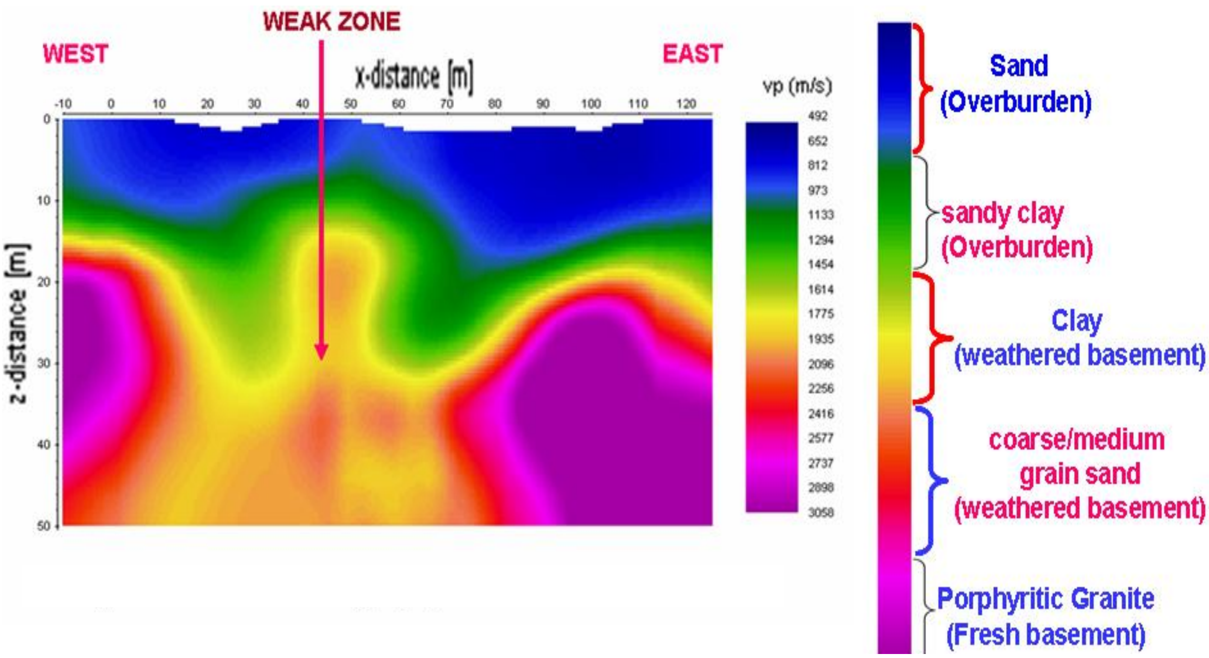

Figure 8: Refraction Tomography Section for Profile CC/

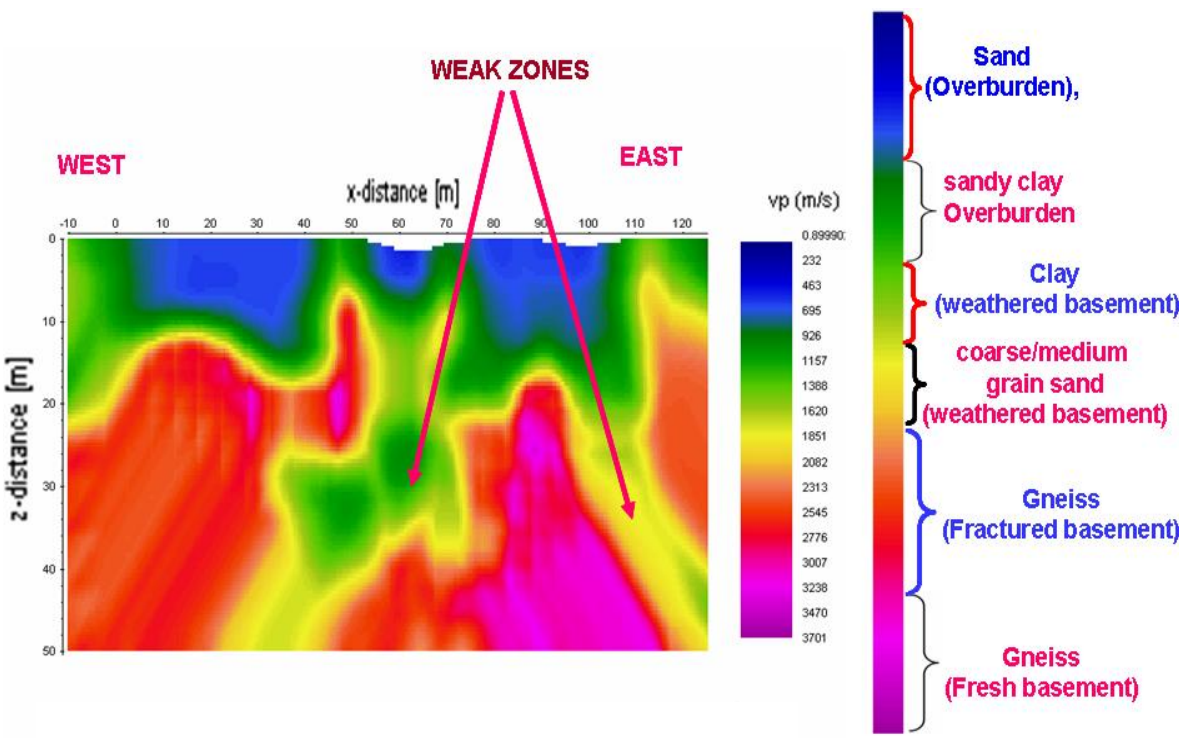

Figure 9: Refraction Tomography Section for Profile DD/

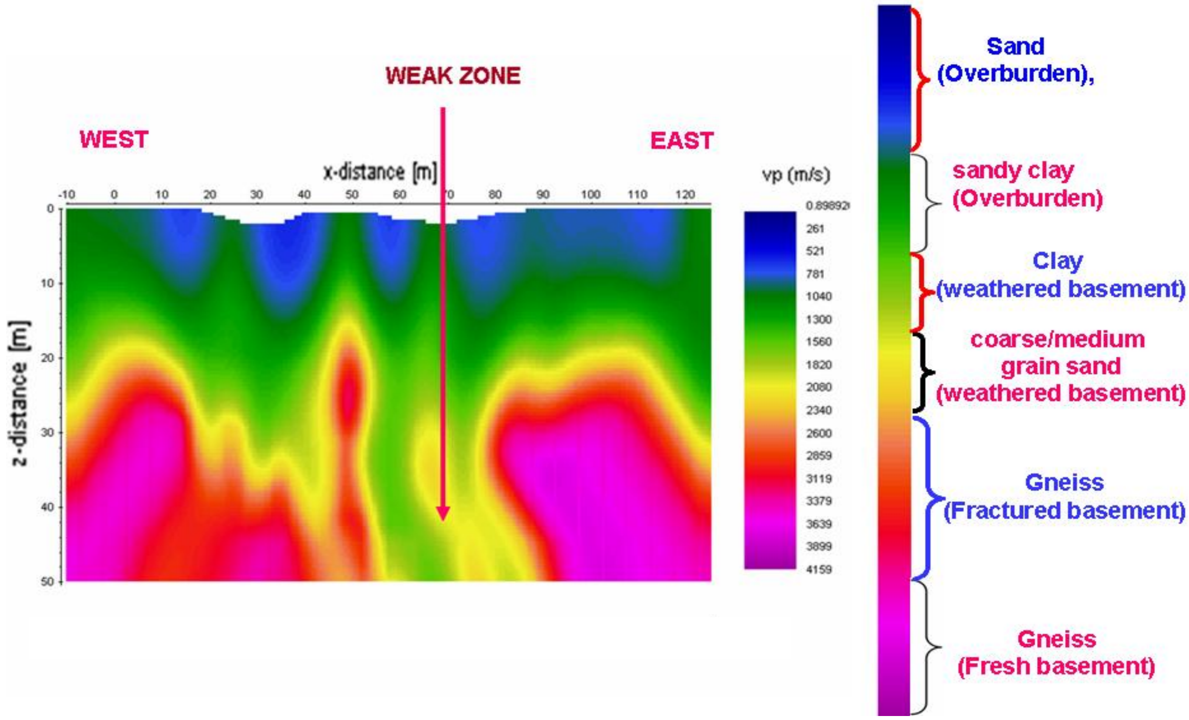

Figure 10: Refraction Tomography Section for Profile EE/

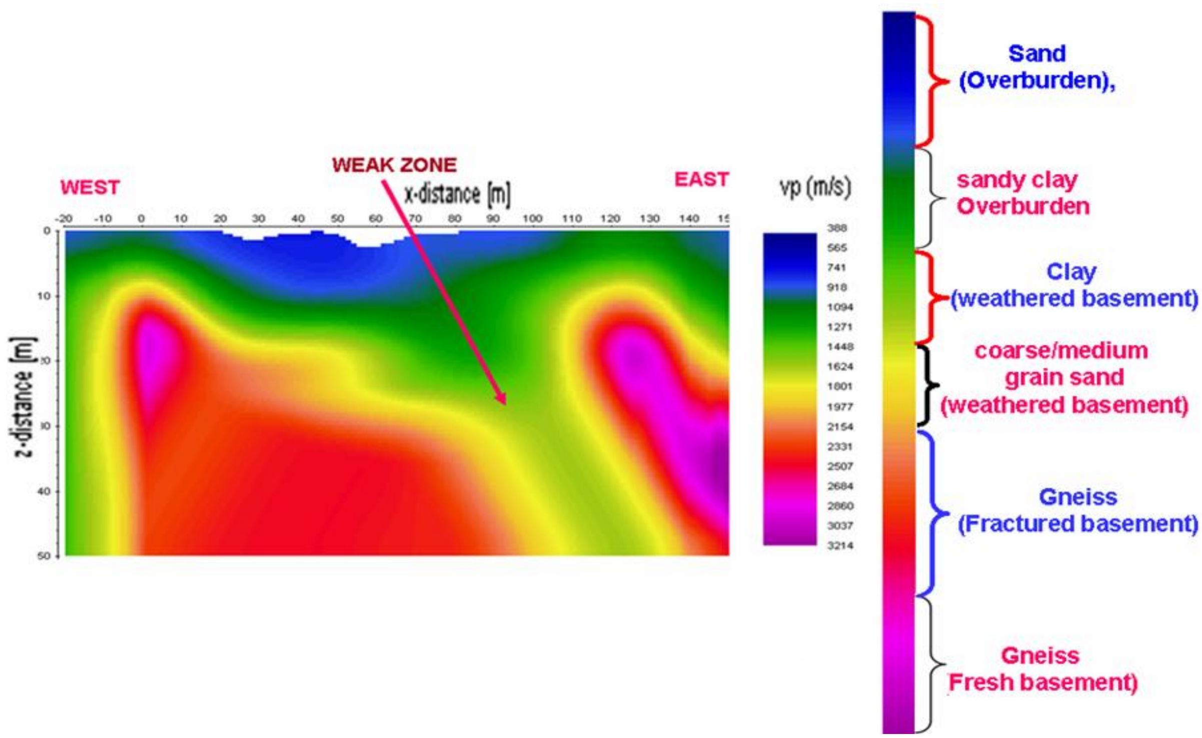

Figure 11: Refraction Tomography Section for Profile FF/

Hence, resistivity tomography data were collected along the profiles. Figures 12 and 13 show the resistivity tomography pseudosections for two of the profiles perpendicular to the valley's strike.

The resistivity tomography pseudosections clearly show sharp disparity in resistivity value of the basement rocks underlying either side of the valley. This further suggests that there are significant differences between the physical properties of the basement rocks on either side of the valley.

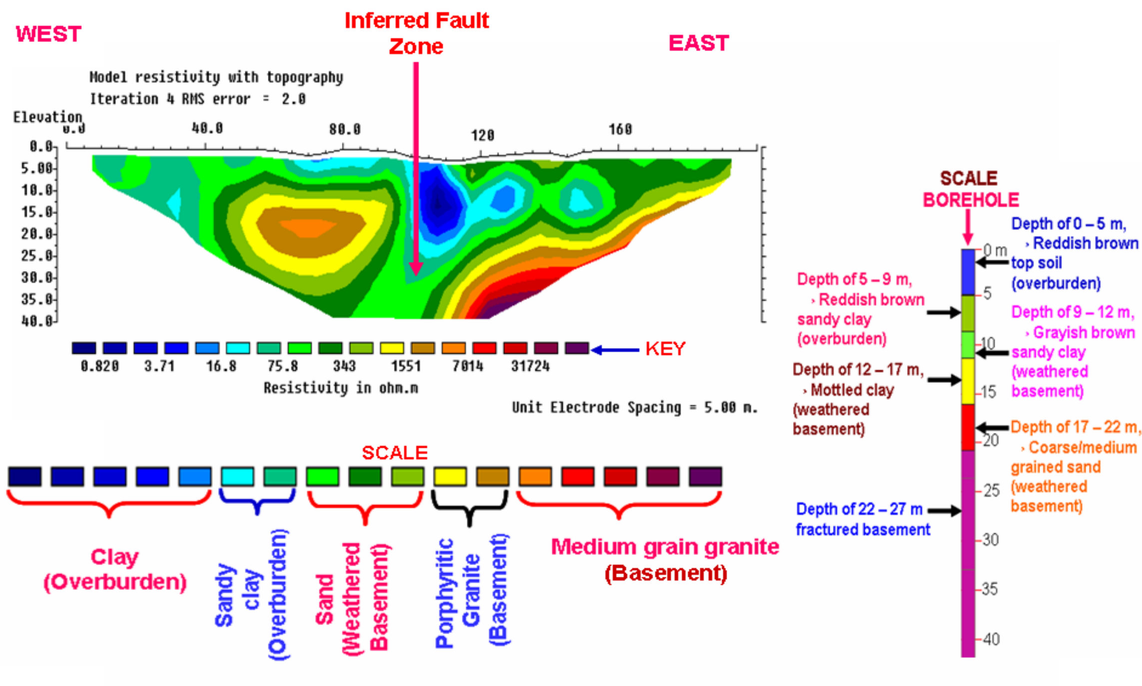

Figure 12: Geologic Interpretation of Geoelectric Section for Profile CC/

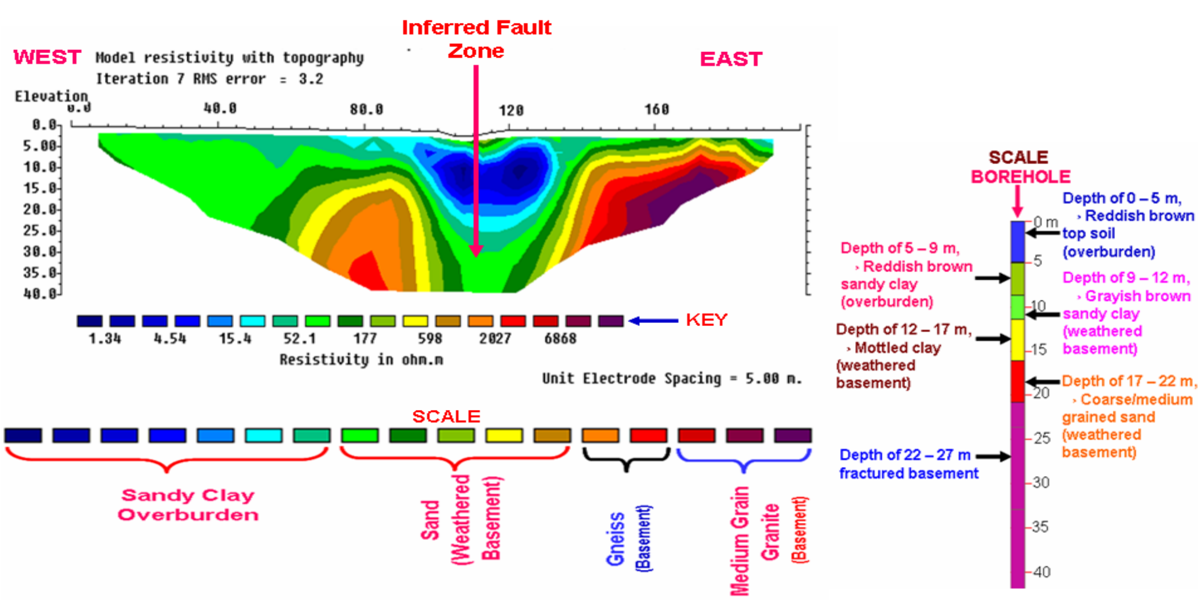

Figure 13: Geologic Interpretation of Geoelectric Section for Profile FF/

DISCUSSION

The results of the tomographic inversion of the seismic data over the study area have suggested that the average minimum depth to the basement in the area is about 28.5 m. This result agrees well with the results of previous works in the Zaria area. For example, Olantinwo (1994) deduced that the depth to the basement in the Zaria area ranges from about 1 m to 65 m.

The seismic tomography inversions have shown on all the profiles that there are zones of low p-wave velocities flanked by high p–wave velocity structures. The low p-wave velocity zones flanked by high velocity structures are most prominent on the tomography sections of the profiles that are perpendicular to the strikes of the valleys (Figures 8, 9, 10, and 11). In most of them, these low velocity zones correspond with the floors of the valley and these are flanked by high velocity basement structures in the subsurface of the valley's walls. These results agree well with the resistivity tomography pseodosections (Figures 12 and 13) which suggest that the basement underlying the floor of the valley has low resistivity values and these are flanked by high resistivity basement structures in the subsurface of the valley's walls.

The presence of low velocity and resistivity zones flanked by high velocity and resistivity zones on the tomograms suggests that the basement in the study area has fractures. The displacement of the rock blocks shown in some tomograms (Figures 9, 10, 11, 12, and 13) suggests the presence of faults in the basement. This suggests that the basement in the study area was once in geologic history subjected to tension and/or compression which caused the breakages and subsequent displacement of the rock blocks. The presence of the low p-wave velocity and resistivity zones on all the tomograms of the profiles perpendicular to the strike of the valley suggests that the faults are most probably parallel to the strike of the valley. These faults facilitated the grabenation of the rock block between them which resulted to the formation of the valley in the study area.

The Zaria Batholithic area generally is characterized by high concentration of network of valleys. The valley around which the data for this study were collected is part of the network. Hence, the valleys in the area generally are most likely fault controlled. This further suggests the geotectonic origin of the valleys in the Zaria area. The spaces due to the displacement between rock blocks were filled up with less dense materials by erosion. The N-S trends of the faults suggested in this work agree well with the general trends of the faults in Zaria area, suggested by Oluyide and Udoh (1989) in their work on fracture systems in Nigeria. Early workers in the Kubanni valley have inferred the presence of deep, well developed faults and fractures in the area. Between 1981 and 1982, Messrs Preussag Ltd., carried out a resistivity survey in Jamaa Kubanni village with the aim of siting a borehole in the village. They inferred from the results of their resistivity data the presence of faults within the bedrock which have caused the downthrow of certain portion of the bedrock, especially, in the south-east part of the area.

The results of the tomographic inversion of the seismic data from the flanks of the valley suggest that the physical properties of part of the basement rocks on either side of the valley differ significantly. For example, the p-wave velocity of part of the basement rock on profile AA$^{/}$ (Figure 6) which is on the eastern side of the valley ranges from about 5120 ms^{-1} – 9093 ms^{-1}. On profile BB$^{/}$ (Figure 7) which is on the western side of the valley, the p-wave velocity ranges from about 2550 – 5831 ms^{-1}. The results of the resistivity tomography pseodosections (Figures 12 and 13) lend support to the clear disparity in the properties of the basement rocks on either side of the valley.

The resistivity tomography pseodosections suggest that the average basement resistivity in the western part of the valley is about 2500 Ωm while the average basement resistivity in the eastern part of the valley is about 12500 Ωm. The differences in the physical properties of the basement rocks on either side of the valley suggest that they differ in lithological compositions and/or crystal texture. This implies that there are different basement rock blocks which have sharp or gradational contacts at the valley. Such contacts of different rock blocks have been reported in the past in Zaria area. For example, McCurry (1970) reported that there are gneisses and granites mostly in the central and eastern parts of Zaria area and the contacts between them are gradational. However, Webb (1972) and Shemang (1990) confirmed the contacts between different rock blocks in Zaria area but suggested that the boundary between the Zaria Granitic Batholith and gneiss unit is sharp and not gradational. In about 1 km south –

east of the study area another contact between porphyritic granite and gneiss has recently been exposed at the floor of a valley by the erosive power of the seasonal stream that flows through the valley. The places having different rock block contacts constitute weak zones which are susceptible to fracturing and subsequent grabenation.

CONCLUSION

Based on the deductions made from the seismic cross-sectional tomograms of the subsurface of the study area, the following it can be inferred that for the study area:

1. Contacts between difference rock blocks and high concentration of fracture and fault zones within the basement in the study area are most probably responsible for the arbitrary and sharp changes of some physical properties of the subsurface measured in the study area.

2. These rock block contacts most likely constitute weak zones which enhanced fracturing and faulting in the study area. The subsidence resulting from parallel faults zones in the area most probably typifies the formation of the valleys which characterized the Zaria Batholithic area.

ACKNOWLEDGEMENT

The authors are immensely grateful to the International Programme in the Physical Sciences, Uppsala University, Sweden, for providing both the grant and equipments used in this project.

REFERENCES

1. ABEM Instruments. 1994. “Terraloc MK6 Reference Manual”. ABEM: Bromma, Sweden.

2. Adeniyi, O.O. 1987. “Gravity Survey of the Older Granite Plutons in the Zaria Area of Kaduna State, Nigeria”. Unpublished M.Sc. Thesis, Department of Physics, Ahmadu Bello University: Zaria, Nigeria.

3. Garba, M.L. and Schoeneich, K. 2003. “A Preliminary Report on the Hydrogeology of Kubanni Dam”. *The Nigerian Journal of Scientific Research*. 4(1):75 – 80.

4. Hore, P.N. 1970. “Weather and Climate in Zaria and Its Region”. In: Mortimore. M.J. (Ed.). “Zaria and Its Region”. Occasional Paper No. 4. Department of Geography, Ahmadu Bello University: Zaria, Nigeria. 41 – 54.

5. Hydro-Skill and Engineering Services, Kaduna 2005. Files on Borehole Records in Ahmadu Bello University, Zaria, Nigeria, Estate Department, Ahmadu Bello University, Zaria.

6. Ike, E.C. 1988. “Late-Stage Geological Phenomena in the Zaria Basement Granites: A Review in the Precambrian Geology of Nigeria”. Geological Survey of Nigeria: Lagos, Nigeria. 83 – 89.

7. Lo, T. and Inderwiesen, P.L. 2000. “Fundamentals of Seismic Tomography”. In: Fitterman, D.V. and Lines, L.R. (Eds.). *Geophysical Monograph Series.* Soc. of Explo. Geophys. No. 6.

8. McCurry, P. 1970. “The Geology of Degree Sheet 21 (Zaria)”. Unpublished M.Sc. Thesis. Geology Dept., Ahmadu Bello University: Zaria, Nigeria.

9. Messrs Preussag Ltd. 1981 – 1982. Files on Borehole Records, Kaduna State Water Board, Kaduna, Nigeria.

10. Olatinwo, M.O. 1994. “Geoelectrical Investigation in the Northern Part of Kaduna State, Nigeria”. Unpublished Ph.D Thesis. Physics Dept., Ahmadu Bello University: Zaria, Nigeria.

11. Oluyide, P.O. and Udoh, A.N. 1989. “Preliminary Comments on the fracture systems of Nigeria”. In: Ajakaiye, D.E., Ojo, S.B., Daniyan, M.A., and Abatan, A.O., (eds.). *Proceedings of the National Seminar on Earthquakes in Nigeria*. National Technical Committee on Earthquakes Phenomena. 97-109.

12. Osazuwa, I.B., Adeniyi, O.O., and Ojo, S.B. 1992. “A Gravity Study of the Older Granite Suite in the Zaria Area of Kaduna State, Nigeria”. *Journal of Mining and Geology*. 28(2):231 – 236.

13. Sandmeier, K.J. 2003. *User’s Guide Manual on REFLEXW Version 3.0 for the Processing of Seismic, Acoustic or Electromagnetic Reflection, Refraction and Transmission Data*. http://www.sandmejer-geo.de.

14. Shemang, E.M. 1990. “Electrical Depth Sounding at Selected Well Sites within the Kubanni River Basin, Zaria, Nigeria”. Unpublished M.Sc. Thesis, Physics Dept., Ahmadu Bello University: Zaria, Nigeria.

15. Webb, P.K. 1972. “Recent Research on the Geology between Zaria and Kaduna”. *Savannah*. 2:241.

ABOUT THE AUTHORS

Prof. Osazuwa Isaac Babatunde is a Professor of Geophysics at Ahmadu Bello University, Zaria, Nigeria. He is the Project Leader of Geophysics Programs in Nigeria under the auspices of International Programme in the Physical Sciences Uppsala University, Sweden. He is a Fellow of the Nigeria Institute of Physics (NIP). He has supervised several Ph.D. theses in various areas of Geophysics. He has particularly made distinct contributions in Gravity Potential Theory and investigations in Nigeria and beyond.

Dr. Ibe Stephen Onyejiuwaka is a Lecturer in the Department of Physics of Federal College of Education Zaria. He holds a Ph.D. degree in Applied Geophysics. His research interests are in the areas of environmental and engineering geophysics.

Dr. Egwuonwu Gabriel Ndubuisi is a Lecturer in the School of Science Technology of Federal College of Chemical and Leather Technology, Zaria, Nigeria. He holds a Ph.D. degree in Applied Geophysics. His research interests are in the areas of environmental and engineering geophysics.

SUGGESTED CITATION

Osazuwa, I.B., S.O, Ibe, and G.N. Egwuonwu. 2009. “Geophysical Investigation of the Origin of Abrupt Changes in Subsurface Properties in Zaria Area, Nigeria”. *Pacific Journal of Science and Technology*. 11(1):551-562.

Pacific Journal of Science and Technology