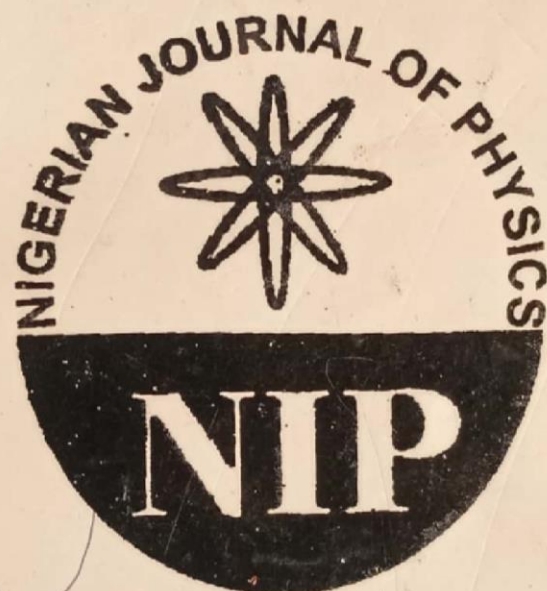

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Near-surface electrical profiling within Precambrian Basement Complex of Nigeria

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Abstract

University of Ilorin Dam Axis, seated on the Precambrian Basement Complex of Nigeria, was profiled using the Wenner array to investigate the vertical contacts and lateral changes in the geologic setting around the Dam axis. Electrode spacing $a = 5\text{ m}$, 10 m , 15 m , 20 m , 25 m and 30 m were used for prospecting the faults and fracture pattern in the area. The survey area lies within the basement rocks in the Western part of Central Nigeria bounded within longitudes $4^\circ 39'52''\text{E}$ and $4^\circ 40'0''\text{E}$, and latitudes $8^\circ 27'5''\text{N}$ and $8^\circ 28'5''\text{N}$. The study area falls within the eastern part of Ilorin metropolis in the tropical climate region and has two distinct seasons of dry and wet seasons. This survey was achieved through five profiles of 120 m length each along the dam axis. Three of these profiles were at the bank of the dam, while the other two were obtained along the stream bank. The linear plot of apparent resistivity (ρ_a) against distance along each profile gave the distribution of resistivity values at each spacing of a across the entire profile and the lithological arrangement of the area. The profiles along the dam bank show low resistivity of three layers namely: wet sand (top soil) of about $90\ \Omega\text{m}$, gravel (mostly saturated) of about $200\ \Omega\text{m}$ and basement (partially weathered) of about $600\ \Omega\text{m}$. Conversely, profiles away from dam bank showed lateritic top soil ranging from $120\text{--}180\ \Omega\text{m}$, thin gravel layer of about $250\text{--}300\ \Omega\text{m}$ and basement complex layer with almost $2577\ \Omega\text{m}$. The 2-D pseudo-sections revealed the depth to unexposed granitic intrusion that appeared in form of dyke in some profiles. Various vertical contacts were identified in the area.

Keywords: Resistivity, Profiling, Equidistance, Traverse, Pseudosection, Dam.

Symbols:

Ω : ohm

ρ_a : Apparent Resistivity

Introduction

Dams are vital elements which stores water for purposes such as human consumption, food production, electricity production, industrial use, and flood protection. The failure of a large modern dam with a large reservoir would not only be spectacular, it would also cause tremendous damage. Dam failure is usually fatal which involves destruction of lives, properties and the ecosystem (International Commission of Large Dams ICOLD 1987) Hence, it is important to note that once a dam is completed, it represents a potential risk in the future, because of several factors acting on the structures. Dam failure could be structural, natural or man-made. It could also be due to prolonged or intensive rainfalls, anomalous seepage, internal erosion and so on. History has shown that flood disaster is not a recent phenomenon, and that its destructive tendencies are sometimes enormous. For

instance, in Nigeria, report has it that serious flood disasters have occurred in Ibadan (1985, 1987 and 1990), Osogbo (1992, 1996, 2002), Yobe (2000), Akure (1996, 2000, 2002, 2004 and 2006) and the coastal cities of Lagos, Ogun, Port Harcourt, Calabar, Uyo, Warri. Geoelectric resistivity survey/profiling is efficient and effective in investigating shallow and near-surface behaviours. This method has its origin in 1912 from the work of Conrad Schlumberger in which Frank Wenner from United State of America (USA) developed a similar idea with different arrangement in 1916 (Kunetz, 1966; Griffiths and Campbell, 1990; Griffiths and Barker, 1993; Dahlin and Loke, 1998; Olayinka, 1999; Olayinka and Yaramanci, 1999; Amidu and Olayinka, 2006 and Aizebeokhai *et al.*, 2009). The specific objective of this study is to detect possible degraded areas that are potentially liable to water infiltration or leakage, and to evaluate the

dynamic properties of the subsurface materials in the area around the Unilorin Dam axis.

Unilorin Dam is within the University of Ilorin permanent site in the west central part of Nigeria (Figure 1) The area lies entirely within the basement rocks in the Western part of Central Nigeria bounded by longitudes $4^{\circ} 39'52''$ to $4^{\circ} 40'0''$ E and latitudes $8^{\circ} 27'5''$ to $8^{\circ} 28'5''$ N. The study site is easily accessible through a moderately wide motorable road that eased the fieldwork. The topography of the area is relatively plain with minor undulations. The city is drained mainly by Asa River and its tributary river such as Aluko, Alalubosa, Okun, Osere, Agba and Oyun River which forms the drainage basin (Jimoh and Ajewole, 2009) The main river within the campus is river Oyun which flows from South-East to North-West.

Materials and Method

Wenner array of constant electrode separations (Figure 2) was employed in the electrical resistivity survey. The separation was increased in steps in order to probe deeper in the subsurface. The terrameter used is 4-electrode system maintained at constant spacing at each sampling profile.

Basic Theory

This makes use of Wenner configuration (Figure 2) of electrical Resistivity, the configuration that provides horizontal contours beneath the center of the array. Due to this, Wenner array is relatively sensitive to vertical changes in the subsurface resistivity below the center of the array. However, it is less sensitive to horizontal changes in the subsurface resistivity. In general, Wenner profiling is good in resolving vertical changes (i.e. horizontal structures), but relatively poor in detecting horizontal changes (i.e. narrow vertical structures). Shown below is electrode arrangement of Wenner Array. (Wenner 1915; Kunetz, 1966; Thomas et al. 1981; Keary and Brooks, 2002)

$$V = IR \text{ ----- 1st Ohm's Law} \quad (\text{Eq. 1})$$

$$R = \ell L/A \text{ ----- 2nd Ohm's Law} \quad (\text{Eq. 2})$$

where ℓ is resistivity of material

The potential at M is given as:-

$$V_M = \{(I\ell)/(2\pi)\} (1/r_{AM} - 1/r_{MB}), \text{ and} \quad (\text{Eq. 3})$$

$$V_N = \{(I\ell)/(2\pi)\} (1/r_{AN} - 1/r_{NB}) \quad (\text{Eq. 4})$$

Hence, the potential difference between M and N, from Eq. 3 & Eq. 4, is

$$\Delta V = V_M - V_N = \{(I\ell)/(2\pi)\} (1/r_{AM} - 1/r_{MB} - 1/r_{AN} + 1/r_{NB}) \quad (\text{Eq. 5})$$

Therefore Resistivity (ℓ) can be expressed as:-

$$\rho = \frac{2\pi\Delta V}{I \left\{ \left(\frac{1}{r_{AM}} - \frac{1}{r_{MB}} \right) - \left(\frac{1}{r_{AN}} - \frac{1}{r_{NB}} \right) \right\}} \quad (\text{Eq. 6})$$

$$K = \frac{2\pi}{\left\{ \left(\frac{1}{r_{AM}} - \frac{1}{r_{MB}} \right) - \left(\frac{1}{r_{AN}} - \frac{1}{r_{NB}} \right) \right\}} \quad (\text{Eq. 7}),$$

and in Wenner array $r_{AM} = a$, $r_{MB} = 2a$, $r_{AN} = 2a$, $r_{NB} = a$, substituting these values into Eq. 7, Eq. 6 becomes;

$$\rho_a = \frac{2\pi\Delta V}{I \left\{ \left(\frac{1}{a} - \frac{1}{2a} \right) - \left(\frac{1}{2a} - \frac{1}{a} \right) \right\}} \quad (\text{Eq. 8})$$

That is,

$$\rho_a = 2\pi a \frac{\Delta V}{I} \quad (\text{Eq. 9})$$

Since $K = 2\pi a$ and if $R = \frac{\Delta V}{I}$, then

$$\rho_a = K \frac{\Delta V}{I} = KR \quad (\text{Eq. 10})$$

where R is the measured resistance from Terrameter and K is the Geometric factor defined above which is a function of the electrode configuration that was adopted in this survey.

Data Acquisition

Horizontal electrical sounding (profiling method), using Wenner array, was chosen to perform this field work. Measurements were done at different electrode spacing's (a). Since, by increasing the electrode spacing more of the injected current flows to greater depths and consequently apparent resistivity values at different depths are obtained. The electrode spacing varied from 5 m up to 30 m in order to cover the formations at different depths in a comprehensive way. So, the field survey was completed at electrode spacing 5, 10, 15, 20, 25, and 30 meters. At $a = 5$ m the area was profiled using 1a spacing. This implies that the distance between the electrodes is equidistant of 5m. Similarly, at $a = 10$ m the profiling was done on 2a spacing.

The linear plots of the data obtained were accomplished using suitable Computer Software, after which the 2-D Resistivity structure were obtained with computer software. Resistivity contrast within the earth portions could indicate layers (Rahaman, 1988), hence, from the linear plots the lithological arrangement of the area were deduced using their resistivity variation.

Results and Discussions

The result of the Constant Separation Traversing (CST) conducted around the Unilorin dam is presented both in Linear Plots and 2-D Resistivity Structure along the traverses surveyed. The geologic equivalence models of lateral resistivity variations are juxtaposed with the linear plots along all the profiles as shown in figures 3 through 12 for profiles A-A' and E-E'.

The lithological arrangement predicted by the linear plots shows that area around the dam comprises of wet sand underlain by lateritic sand, saturated gravel, weathered

basement and basement complex. In the same vein, the lithological arrangement of profiles beside the stream flank depicts combination of laterite soil, gravelly layer, and basement complex.

The 2-D resistivity structures of the profiles are represented in figures 13 through 17. This gives pseudosection equivalence which is a phase diagram showing the fields of different equilibrium mineral assemblages for a single bulk-rock composition in the area.

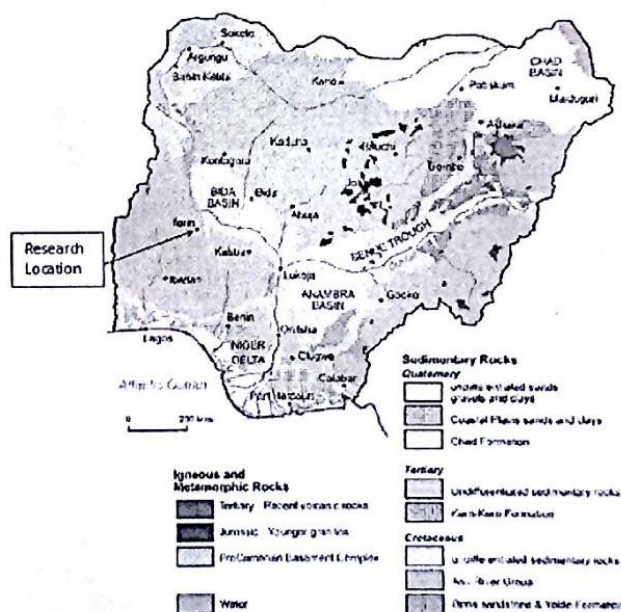
Profile A-A¹ shows resistivity variation which ranges from 76 Ωm to 1068 Ωm . This is about 20 m away from the dam flank. The 2-D resistivity structure gives shallow low resistivity at the top soil of about 100 Ωm between 35.0 m-77.5 m away from the starting point. The depth of this low resistivity is about 5.0 m, after which the resistivity increases to about 500 Ωm with depth of about 3.0 m beneath the Earth Crust. A Dyke-like structure was observed in this profile from the depth of about 10.0 m along 27.5 m-77.5 m with resistivity ranges between 1515 Ωm -12735 Ωm .

The 2-D resistivity structure of profile B-B¹ is similar to profile A-A¹. The little difference in their Pseudo-Section is due to the distance away from the dam flank. This profile is about 50 m away from dam. The dyke observed in profile A-A¹ also manifested in profile B-B¹ with higher resistivity value. Therefore we can account the relative low resistivity of the dyke found in profile A-A¹ to the saturation of water received by the profile. The shallow low resistivity zone

found in profile A-A¹, between 45 and 67 m from the beginning of the profile narrowed down in diameter in profile B-B¹ to between 54 and 61 m with a depth of about 4 m. Likewise a weak zone is observed towards the end of the profile which depicts presence of saturated soil.

The 2-D resistivity structure of profile C-C¹ shows low resistivity distribution at the top-soil. The resistivity structure of this profile is relatively uniform except at the point 72.5 m where there is high resistivity of about 1200 Ωm which depicts the presence of basement at this point. Though this basement shows low resistivity as it moves down at this point, this indicates that either this basement is fractured or weathered showing vertical contact. The top-soil low resistivity slightly steep down its depth and it's about 9 m at the point 50 m-57.1 m from starting point. The resistivity distribution is high at the end but relatively low in the middle of the profile.

The 2-D resistivity structure of profile D-D¹ shows presence of numerous vertical contacts. There is relative high resistivity value from the starting point to about 20 m along the profile. Low resistivity was found after this zone which is due marshy structure of the area, which subtends to about 42.5 m. The relative high resistivity continues to about 75 m away from the starting point. There is a vertical contact after this point, which shows very high resistivity of about 798 Ωm .



(After: Rahaman, 1988)

Fig. 1: Simlified Geology of Nigeria showing the Study Site

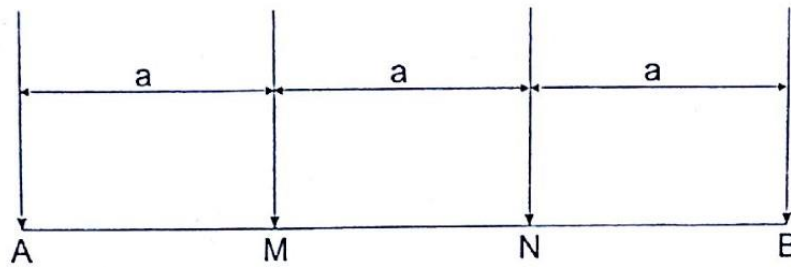


Fig. 2: Wenner electrode Configuration

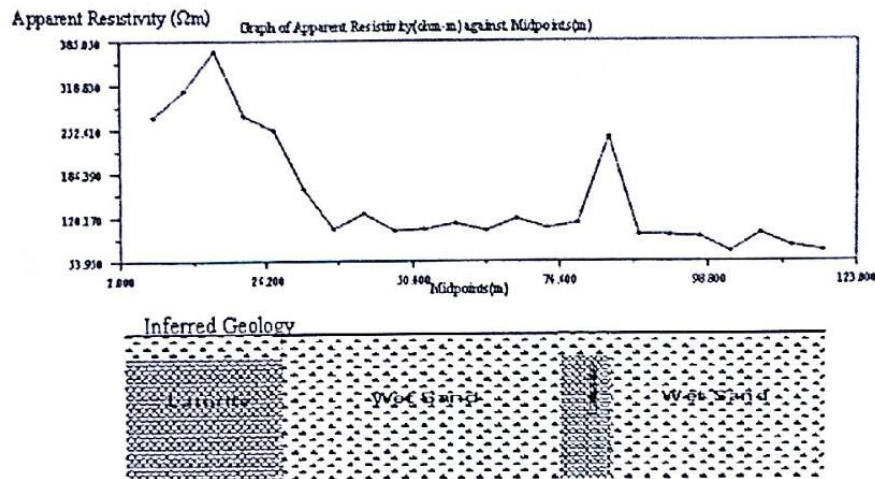


Fig. 3: Geology Equivalence for Traverse AA' at $a = 5$ m

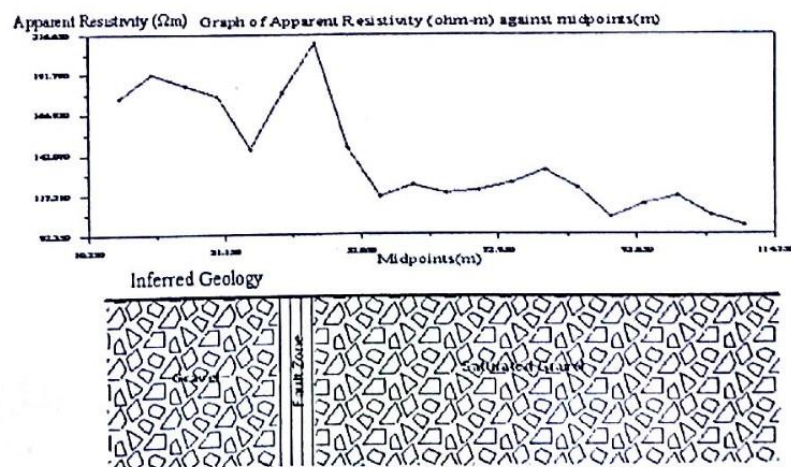
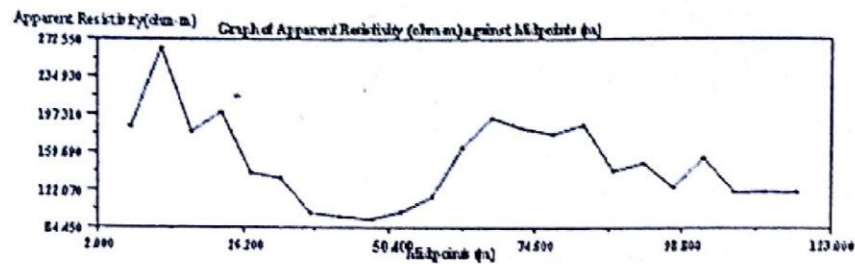


Fig. 4: Geology Equivalence for Traverse EE' at $a = 5$ m



Inferred Geology

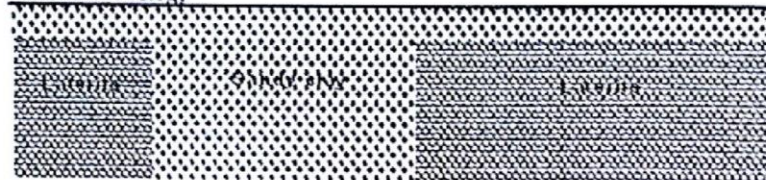
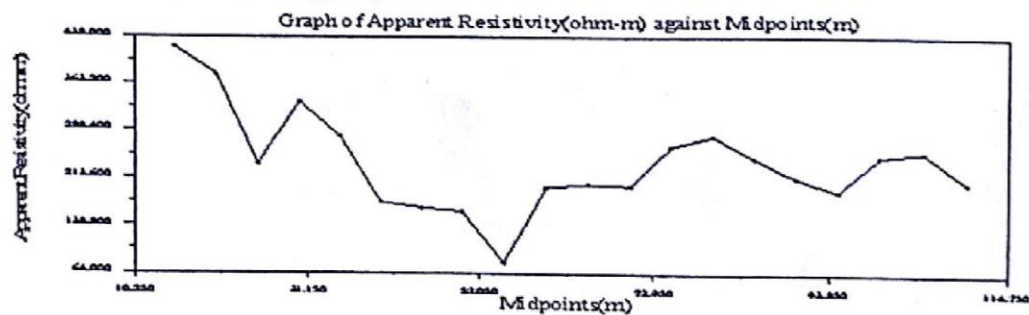


Fig. 5: Geology Equivalence for Traverse AA' at a = 10 m



Inferred Geology

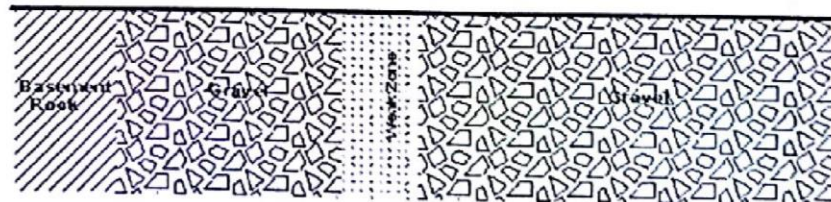
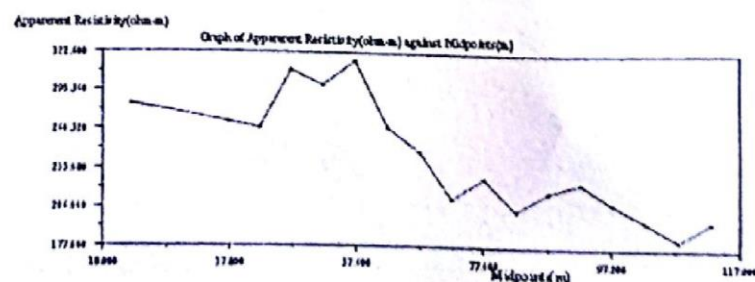


Fig. 6: Geology Equivalence for Traverse EE' at a = 10 m



Inferred Geology



Fig. 7: Geology Equivalence for Traverse AA' at a = 15 m

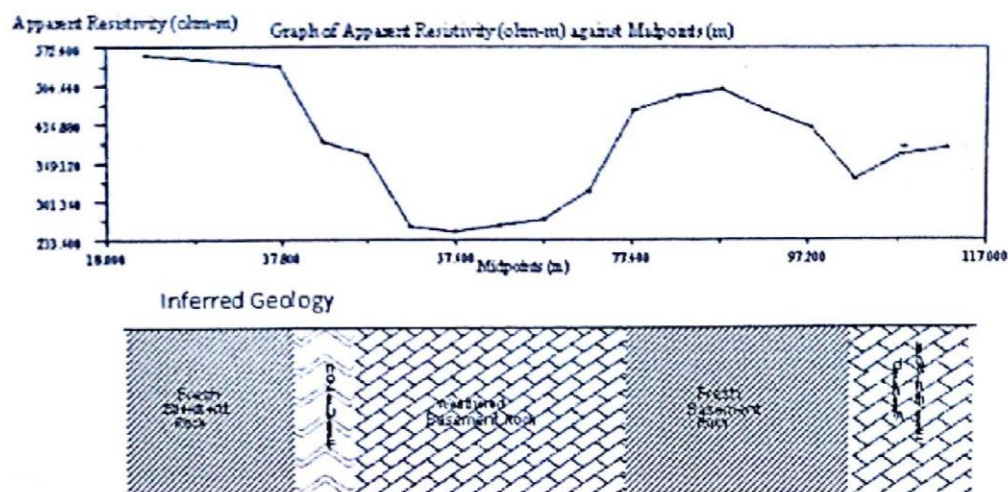


Fig. 8: Geology Equivalence for Traverse EE' at $a = 15$ m

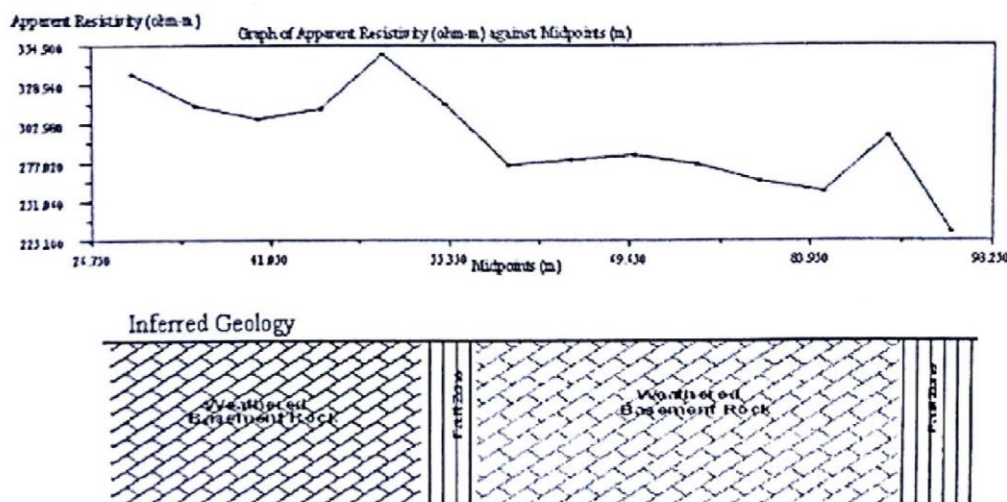


Fig. 9: Geology Equivalence for Traverse AA' at $a = 20$ m

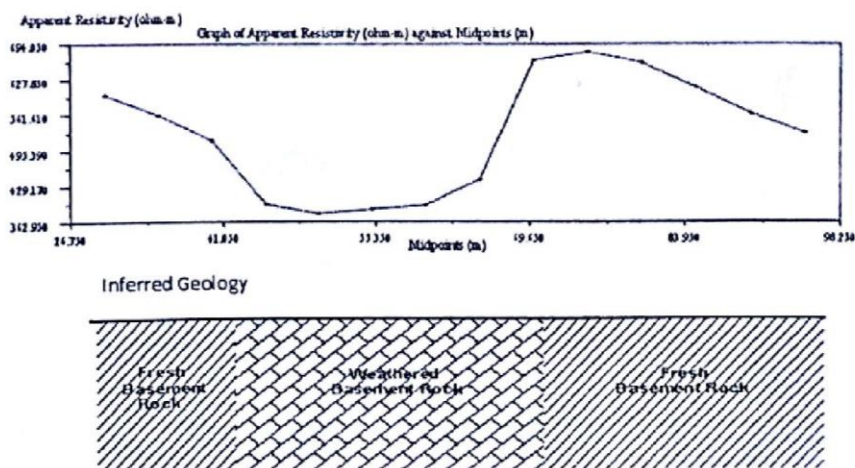


Fig. 10: Geology Equivalence for Traverse EE' at $a = 20$ m

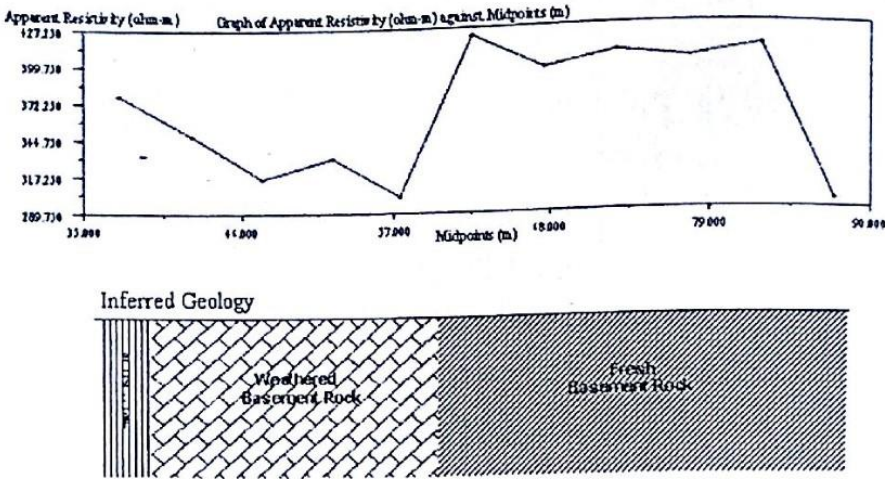


Fig. 11: Geology Equivalence for Traverse AA' at a = 25 m

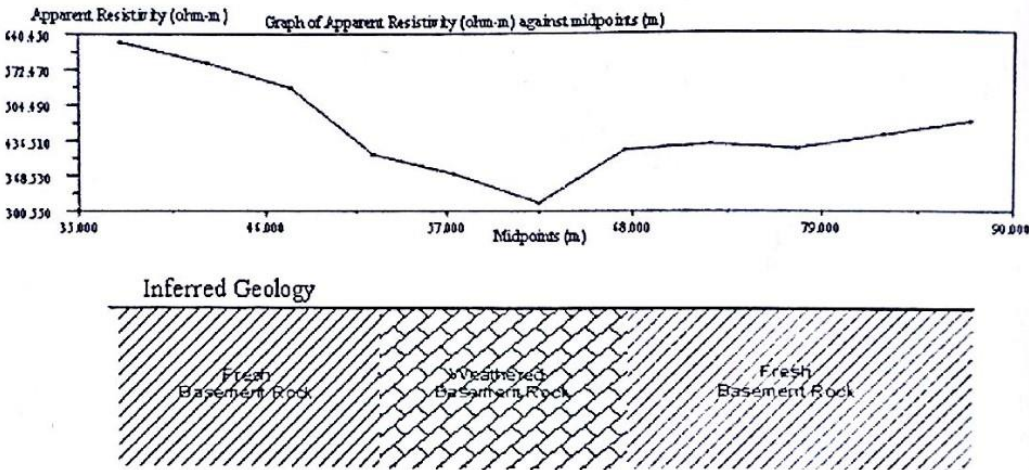


Fig. 12: Geology Equivalence for Traverse EE' at a = 25 m

UNILORIN DAM (2-D Resistivity Structure)

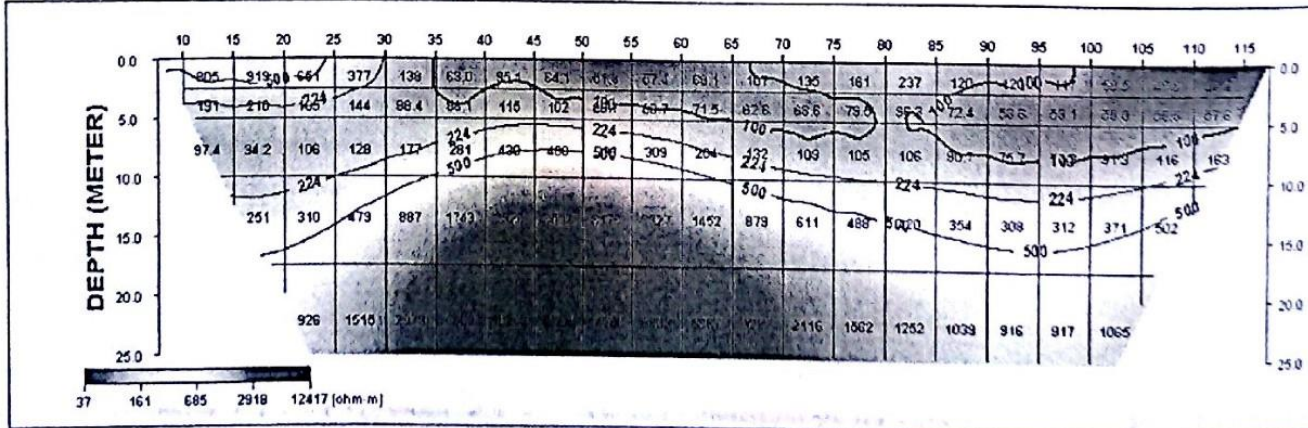
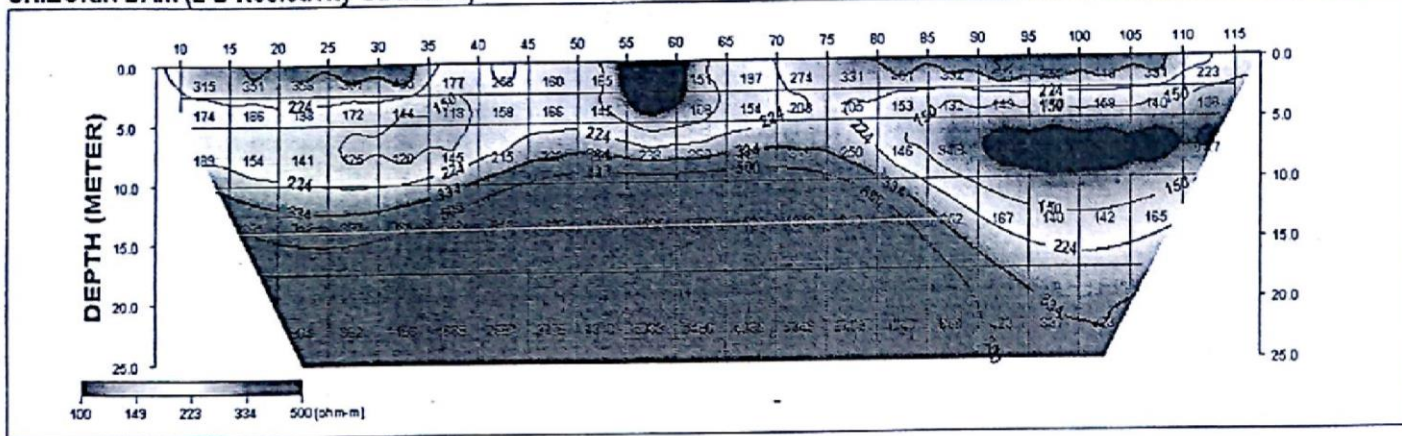
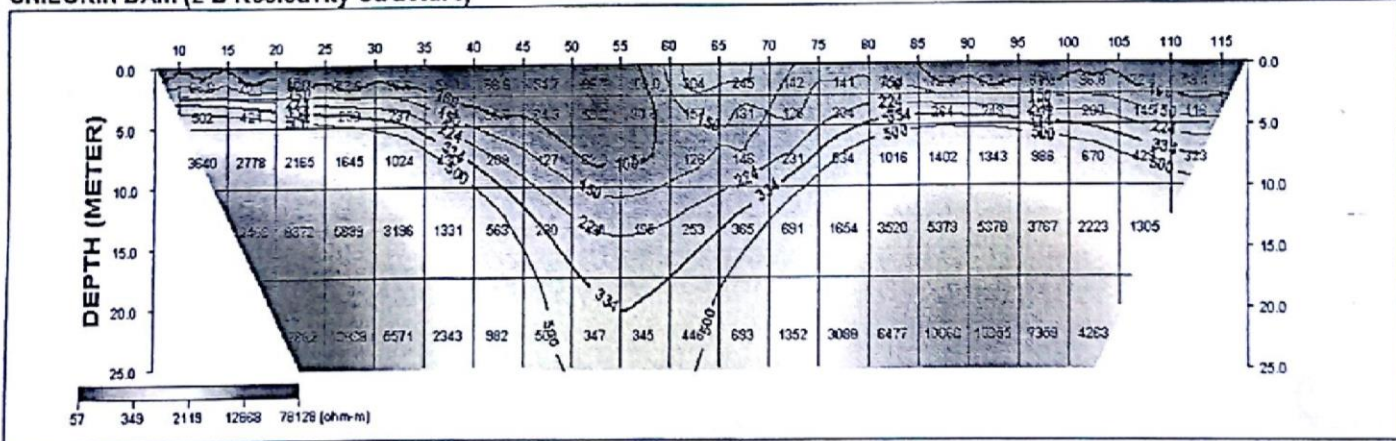


Fig. 13: Pseudosection and 2-D Resistivity Structure along Traverse A – A'

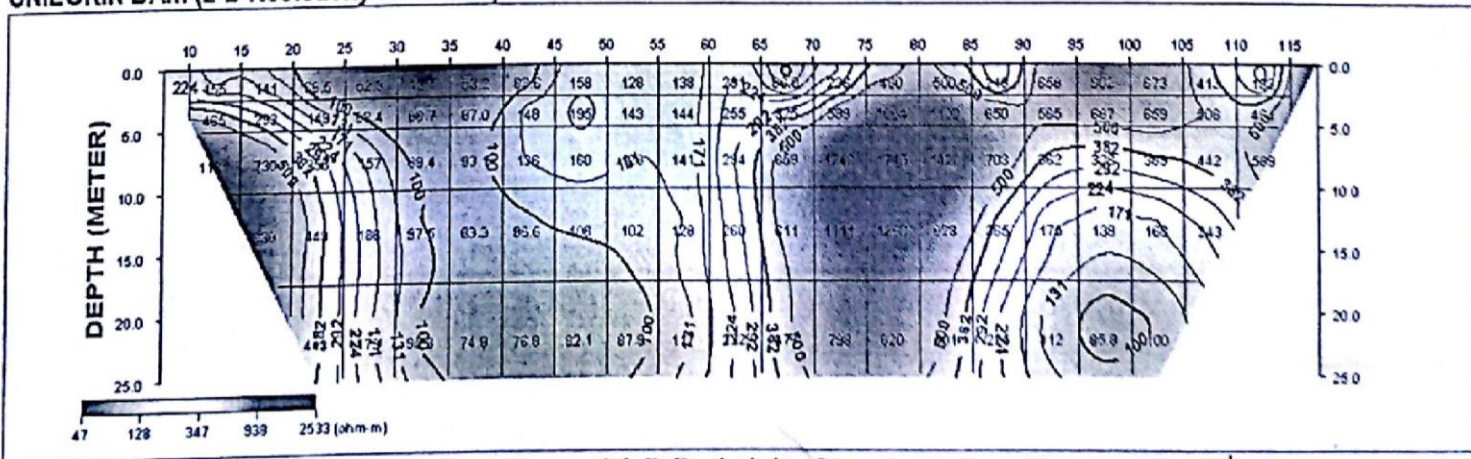
UNILORIN DAM (2-D Resistivity Structure)

Fig. 14: Pseudosection and 2-D Resistivity Structure along Traverse B – B¹

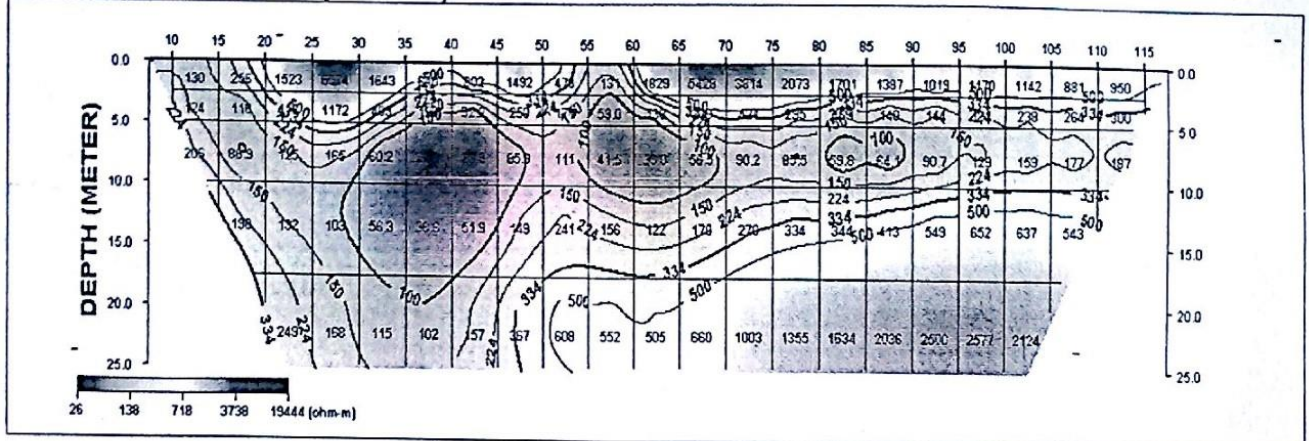
UNILORIN DAM (2-D Resistivity Structure)

Fig. 15: Pseudosection and 2-D Resistivity Structure along Traverse C – C¹.

UNILORIN DAM (2-D Resistivity Structure)

Fig. 16: Pseudosection and 2-D Resistivity Structure along Traverse D – D¹.

UNILORIN DAM (2-D Resistivity Structure)

Fig. 17: Pseudosection and 2-D Resistivity Structure along Traverse E – E¹

Finally, the 2-D resistivity structure of profile E-E¹ shows high resistivity at the top-soil which ranges from 334 Ωm –6574 Ωm with depth of about 5.0 m. But internal Crust has relative low resistivity structure across the profile. But at point 27.5 m–45.0 m from starting point, there is a spot with very low resistivity value of about 18.2 Ωm which depicts the presence of fake aquifer at this point. This is because this low resistivity discontinues immediately.

Conclusion

Geological vertical contacts, faults and fractures are better identified and precisely located using Wenner configuration of multiple scales ranging from a = 5 m, 10 m, 15 m, 20 m and 30 m. The geophysical analysis of Ilorin dam with the pseudo-sections of profile A-A¹ and B-B¹ looks similar, they share the same weak zones and fractures, and likewise their depth to basement is relatively equal. This shows that they both share the same lithological arrangement. The fracture pattern of the study area is unevenly distributed. Fractures are found along profile A-A¹ and E-E¹, also the depth to the basement in the study area is shallow. The topography of the area is relatively plain with minor undulations. Further analysis of dams in and around the geological area using Wenner configuration are suggested to be carried for clearer result.

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