

## Fracture Determination Using Azimuthal Schlumberger and Offsetwenner Array in Basement Complex of Northwestern Nigeria

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**Abstract:** Two surface azimuthal resistivity sounding measurements employing the Schlumberger and offset Wenner arrays were conducted at the Kaduna Polytechnic main campus, Northwestern Nigeria. The objectives were to compare the two electrode arrays in detecting and delineation of fracture systems as an aid in identifying suitable areas for groundwater exploration, siting sewage and waste disposal sites. Resistivities as functions of azimuths are presented as polygons of anisotropy and the computed coefficient of anisotropy ( $\lambda$ ) for the array varies between 1.12 to 1.29, 1.08 to 2.00 for the Schlumberger and offset Wenner arrays, respectively. These  $\lambda$  values are indicative of homogeneously anisotropic ground. However, analysis of the offset Wenner results was successfully used to differentiate between structures which have a  $180^\circ$  azimuthal symmetry (fracture anisotropy) and those which have a  $360^\circ$  azimuthal symmetry (dipping layer and lateral change in resistivity). The results of the survey show that the Offset Wenner array is the best field azimuthal resistivity sounding technique to determine sources of electrical anisotropy.

**Keywords:** Anisotropy, azimuthal, kaduna, offset wenner, schlumberger

### INTRODUCTION

Azimuthal resistivity measurement is a modified resistivity method where the magnitude and direction of the electrical anisotropy are determined. An electrode array is rotated about its center so that the apparent resistivity is observed for several directions (Taylor and Fleming, 1988). It is generally assumed that the anisotropy is caused by presence of fluid – filled fractures in a relatively resistive rock or soil. Azimuthal resistivity has been used to determine fracture geometry in crystalline rocks and glacial till by Lane *et al.* (1995), Carlson *et al.* (1996), Ritzi and Andolsek (1992), Jansen and Taylor (1996) and Chapman and Lane (1996). One of the key problems with azimuthal resistivity method is its sensitivity to lateral heterogeneities. A site exhibiting significant lateral changes in resistivity can produce azimuthal resistivity measurements where the effects of anisotropy are entirely masked by the effects of heterogeneity. Much of the published work based on this method does not account for the possibility of data corruption from lateral changes in resistivity and in fact might be presenting erroneous conclusion (Watson and Barker, 1999). Watson and Barker (1999) and Busby (2000) present argument that at site where the electrical anisotropy is to be determined based on single isolated measurements, only the offset Wenner electrode array

should be used. The offset Wenner array identifies observations that only true electrical anisotropy is interpreted. The offset Wenner array does not, however, allow any interpretation of anisotropy at sites dominated by heterogeneity. The present work employs the offset Wenner and Schlumberger electrode arrays to investigate fracture anisotropy at Mambila village (boy's hostel) of Kaduna polytechnic, Tudun Wada Campus, Kaduna state, Nigeria with the following objectives:

- To compare the effectiveness of the Offset Wenner and Schlumberger resistivity sounding in the determination of electrical resistivity anisotropy.
- To quantitatively determine anisotropy coefficient from both spread and compare their result
- Relate the Geophysical results to existing Geology of the area.

**Site description:** The Kaduna Polytechnic Tudun Wada main campus (Fig. 1) lies within the area of the Basement Complex of Northern Nigerian. The Basement complex includes all rock older than late Proterozoic (McCurry, 1976) and is composed mainly of gneiss, migmatite, granites and some extensive areas of Schists, Phyllites and Quartzite (Baimba, 1978; Preeze and Barber, 1965). The whole Basement has been through at least two tectono-metamorphic cycles

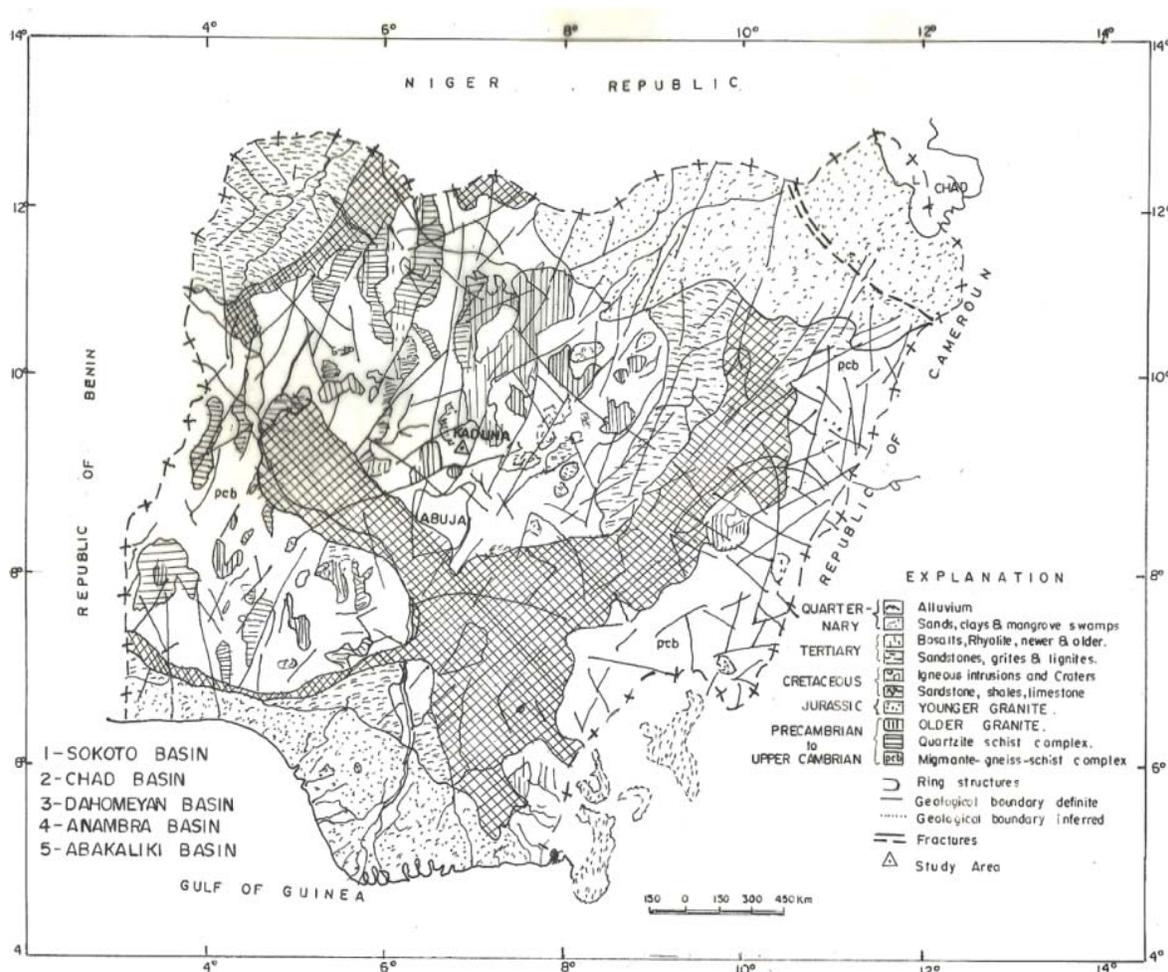


Fig. 1: Map of fracture patterns of Nigeria showing the study area (Geological survey of Nigeria sheet 2516)

and consequent metamorphism, magnetization and granitization extensively modified the original rocks so that they generally occur as relict rafts and xenoliths in migmatites and granites (McCurry, 1976). Their rocks are hard, with low permeability and generally not water bearing. The study area has a typical Savannah climate with distinct wet and dry seasons. The rainy season extends from March/April to October/ November and the dry season between December and March. Average annual rainfall for Kaduna is 1270 mm (Eduvie, 2003). Rainfall generally reaches a peak in august. Temperature varies between less than 15°C around December /January and 32°C in March/April.

#### MATERIALS AND METHODS

**Schlumberger four-electrode array:** Two DC resistivity sounding points named A & B (Fig. 2) were investigated using standard Schlumberger four-electrode array with the ABEM Terrameter SAS 300

equipment. The points were separated by 20 m and maximum current electrode (AB/2) expansion of 20 m and potential electrode expansion (MN/2) of 1 m was used. The electrode configuration was rotated about a fixed point at an increment of 45° in four azimuthal directions. The measured resistance  $R$  ( $\Omega$ ) was converted to apparent resistivity  $\rho_a$  ( $\Omega m$ ) using the appropriate geometric factor. Resistivity as a function of azimuth in radial coordinates were plotted to produce polygons of anisotropy. Apparent coefficient of anisotropy was calculate using the relationship (Mota *et al.*, 2004):

$$\lambda_a = \sqrt{\rho_{max} / \rho_{min}} \quad (1)$$

where  $\rho_{max}$  is the apparent resistivity measure along the ellipse major axis;  $\rho_{min}$  apparent resistivity measure along the ellipse minor axis direction.

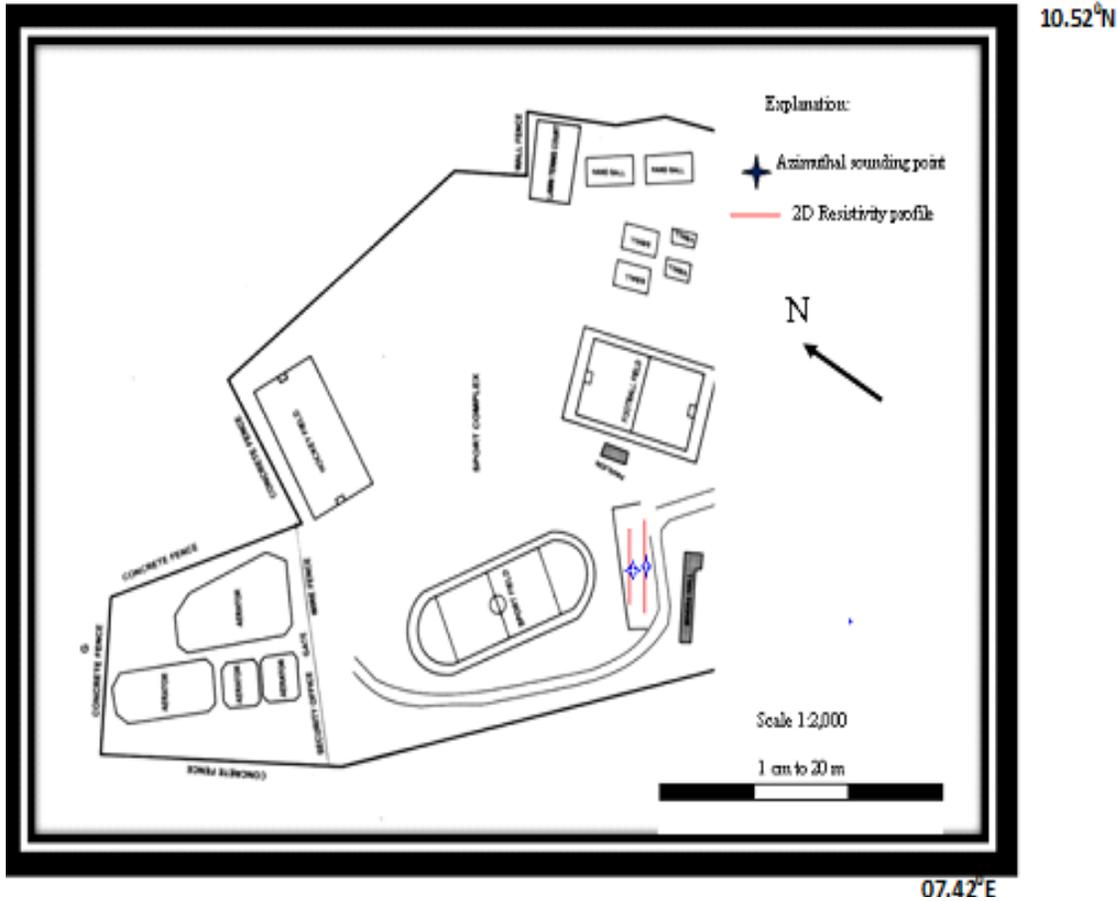


Fig. 2: Topographic map of the study area showing the sounding points

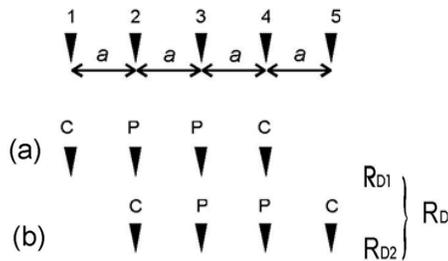


Fig. 3: Offset Wenner electrode arrangement and resistance measurement. a) The five equally spaced electrodes, b) the measurement of the two resistances RD1 and RD2, the average of which provides RD. P and C are potential and current electrodes respectively and  $a$  is the electrode spacing (After Watson and Barker, 2005)

**Offset wenner array:** The offset Wenner method is an improvement of the Wenner array which measures resistance using five equally spaced electrodes. Measurement of ground resistances are made using the

left four electrode, giving  $R_{D1}$  and then the right four electrodes, giving  $R_{D2}$  (Fig. 3). Analysis of the behavior of these two Wenner resistances as a function of both the azimuthal and electrode spacing can enable differentiation between the true anisotropy and other geological models (Watson and Barker, 1999). Also, Busby (2000) has shown that for the rockmass to be considered as anisotropic and homogeneous, the anisotropy measure must exceed the measure of dispersion caused by in homogeneity. This can be expressed by the simple dimensionless quotient:

$$\frac{\sigma(|\rho_D|)}{\sigma(|\rho_{D1} - \rho_{D2}|)} \quad (2)$$

where,  $\sigma(|\rho_D|)$  is the standard deviation of the average offset measurement and  $\sigma(|\rho_{D1} - \rho_{D2}|)$  is the standard deviation of the absolute difference between the two offset measurements. When the measures of anisotropy and dispersion are equal, the quotient has a value of 1.0 and the variation due to anisotropy is equal to that due to in homogeneity. A value greater than one indicates

that the variation due to anisotropy is greater than that due to inhomogeneity, whilst values less than one indicate the reverse. Equation (2) is defined as homogeneity index. A maximum of 15 m electrode separation (a) was used for the offset Wenner array due to space constrain and the two points were investigated in four azimuthal directions as the case with the

Schlumberger configuration. Equation (1) was used to calculate the apparent coefficient of anisotropy.

### RESULTS AND DISCUSSION

Figure 4 shows the Radial graph at sounding point A for the Schlumberger array at AB/2 spacings of 10,

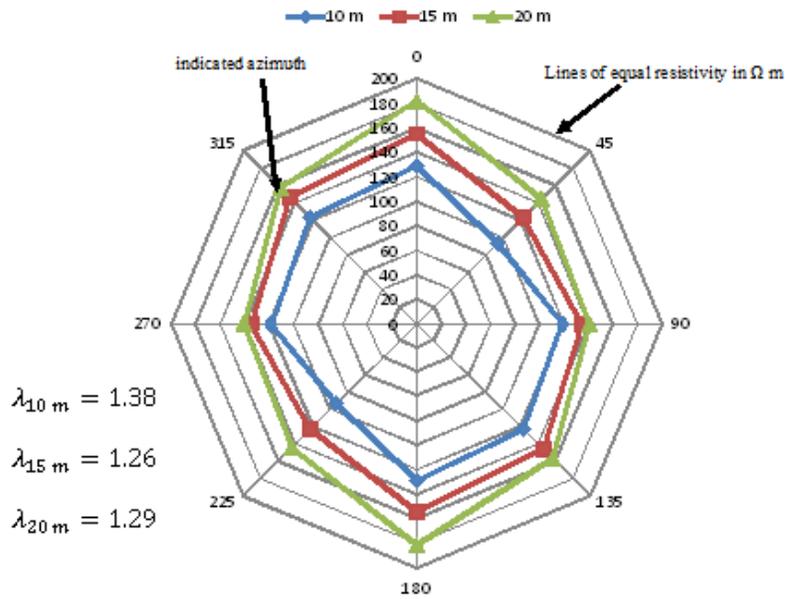


Fig. 4: Radial graph along profile A (Schlumberger array)

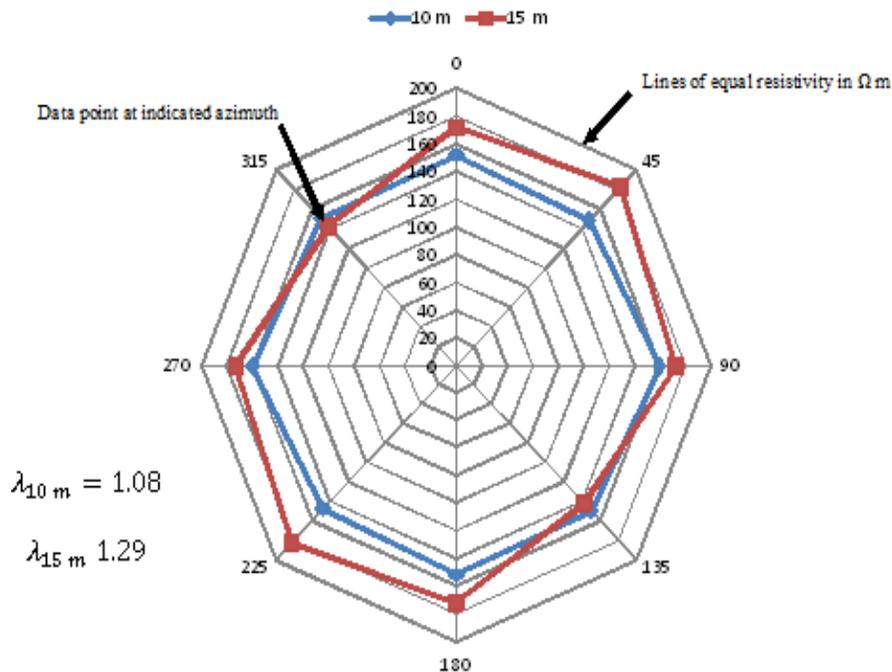


Fig. 5: Radial graph along profile A (offset Wenner array)

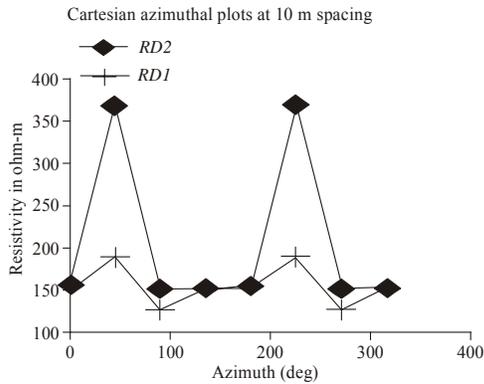


Fig. 6: Cartesian azimuthal graph (10 m)

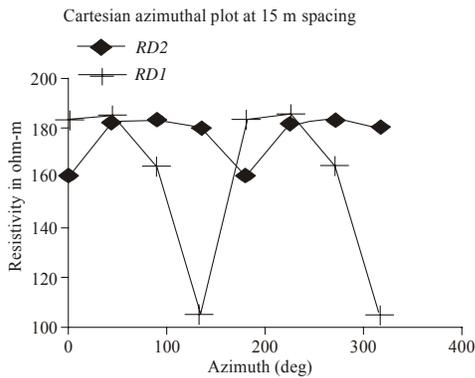


Fig. 7: Cartesian azimuthal graph (15 m)

15 and 20 m. The figures produced are generally elliptical, which are departures from the circular pattern characteristics of a homogeneously isotropic subsurface.

The coefficient of anisotropy ( $\lambda$ ) varies between 1.26 and 1.39 and increases in magnitude with increasing electrode spacings. These values are diagnostic of anisotropic medium given that for homogeneously isotropic medium,  $\lambda = 1$ . The direction of maximum apparent resistivity which is interpreted as the direction of electrical anisotropy (Habberjam, 1975) is constant in the N-S direction for all the spacings. Figure 5 is the corresponding Offset Wenner array radial graphs of  $R_D$  (obtained from the mean of  $R_{D1}$  and  $R_{D2}$ ). Due to constrain imposed by space, the maximum electrode spacing (a) was 15 m. With coefficient of anisotropy values of 1.08 and 1.29 at the investigated depths, the figures are indicative of homogeneously anisotropic medium. Unlike the figures obtained from the schlumberger array, the direction of electrical anisotropy varies with the increasing electrode spacings. At an electrode spacing of 10 m, electrical anisotropy is in the N-S direction while for electrode spacing of 15 m it is in the NE-SW direction. Though both Fig. 4 and 5 depicts elliptical shapes, the ratio of the long to short axes are quite low which is indicative of the absence of fracturing at these depths (Skjernaa and Jorgensen, 1993). To corroborate this conclusion, Cartesian azimuthal graphs using the Offset Wenner data at the 10 m & 15 m spacings were produced. Form the Fig. 6 and 7 it is apparent that the ground is not homogeneously anisotropic as the values of  $R_{D1}$  and  $R_{D2}$  for both spacings differ significantly according to the orientation of the configuration but is dominated by a lateral change in resistivity. According to Watson and Barker (1999), electrical anisotropy can only be attributed to fracture anisotropy when  $R_{D1}$  and  $R_{D2}$  rise and fall together with rotation of the array. The homogeneity index calculated using equation 2 was

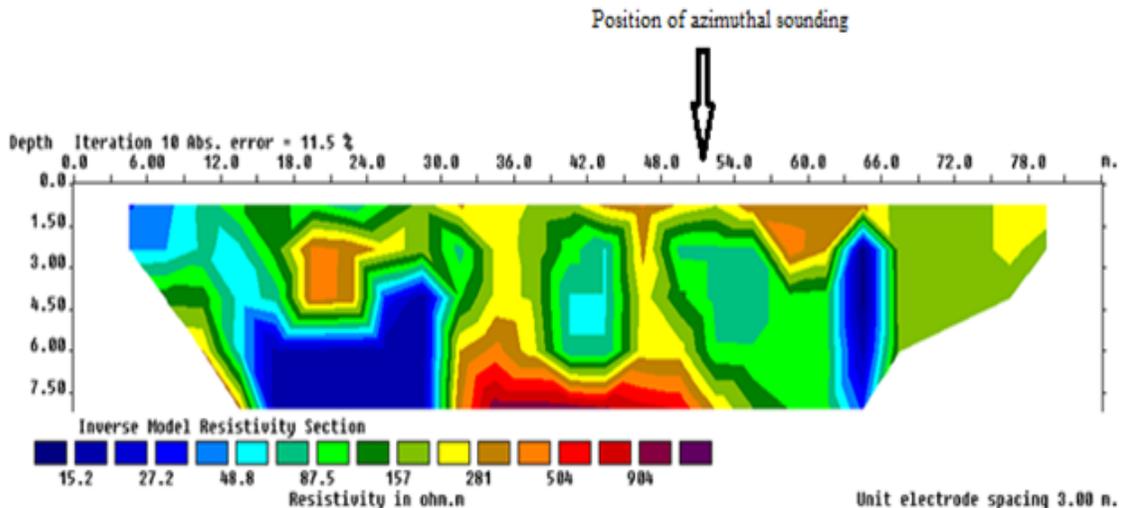


Fig. 8: Electrical image along profile A

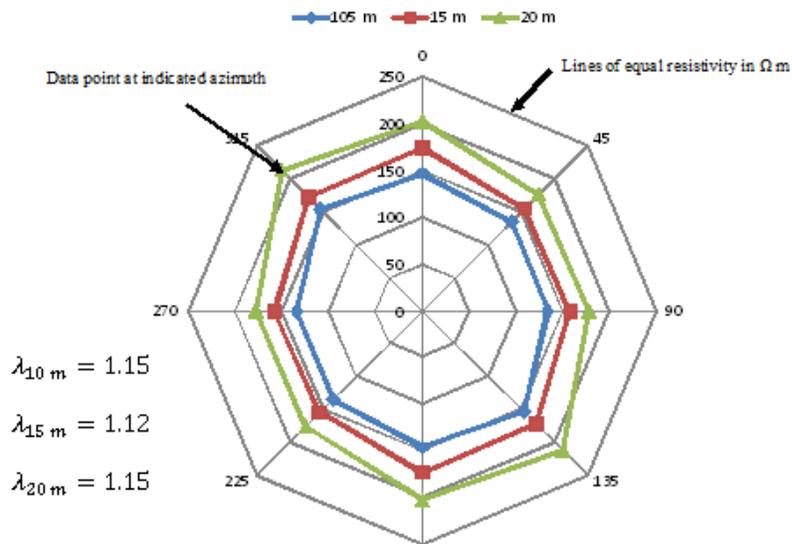


Fig. 9: Radial graph along profile B (Schlumberger array)

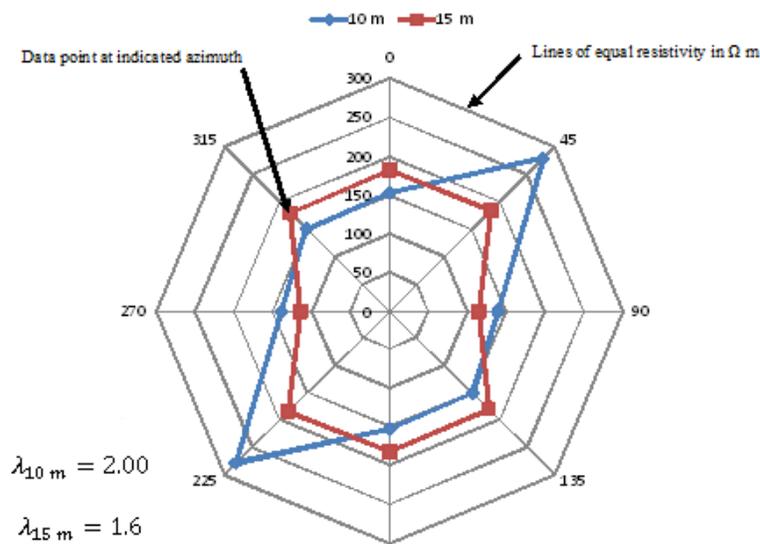


Fig. 10: Radial graph along profile B (offset Wenner array)

0.39 and 0.56 for the 10 and 15 m spacings, respectively. This suggests that the effects of heterogeneity of the rockmass are too great for anisotropic homogeneous effects to be considered. Also, variations due to heterogeneity (the lateral resistivity variations) were confirmed by measurement of an electrical image (Fig. 8). The 2D resistivity model obtained based on the robust method inversion routine clearly indicates lateral resistivity variations in the study area.

Figure 9 is the radial graph for the Schlumberger electrode configuration for AB/2 spacings of 10, 15 and

20 m at sounding point B. The elliptical pattern of the graphs indicates homogeneously anisotropic ground. The coefficient of anisotropy ( $\lambda$ ) varies between 1.12 and 1.15 whilst the N-S direction controls the electrical anisotropy at these depths. The elliptical patterns of the radial graphs of  $R_D$  obtained from the Offset Wenner array are quite distinct from those of the Schlumberger array (Fig. 10). The ratios of the long to short axes are quite high, hence the high values of 2.0 and 1.6 obtained as coefficient of anisotropy. The value of 0.56 calculated as homogeneity index for the 10 m spacing in addition to the relative behavior of  $R_{D1}$  and  $R_{D2}$

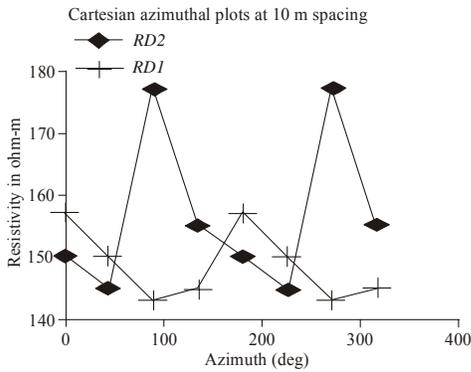


Fig. 11: Cartesian azimuthal graph along profile B (10 m)

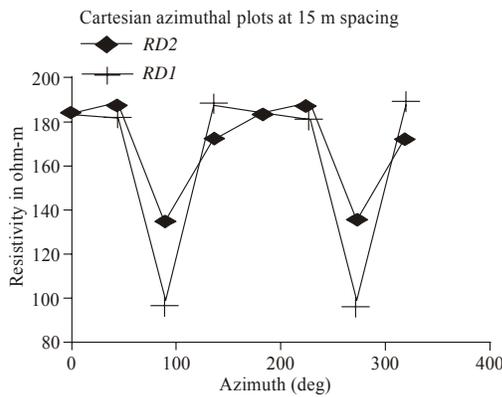


Fig. 12: Cartesian azimuthal graph (15 m)

(Fig. 11) are indicative of effects due to heterogeneity despite the fact that the apparent coefficient of anisotropy (2.00) is the highest obtained. In the Cartesian azimuthal graph corresponding to 15 m spacing (Fig.12),  $R_{D1}$  and  $R_{D2}$  rise and fall together as a function of azimuth and the homogeneity index calculated for the 15 m electrode spacing supports the results of the relative behaviour of  $R_{D1}$  and  $R_{D2}$

returning a value of 2.01 in accordance with the interpretation of anisotropic homogeneous ground. Thus, the value of 1.6 obtained as coefficient of anisotropy can be attributed to fracture anisotropy and in view of the fact that the coefficient of anisotropy ( $\lambda$ ) has been shown to have the same functional form as permeability anisotropy, a higher coefficient of anisotropy implies higher permeability anisotropy (Boadu *et al.*, 2005; Bespalov *et al.*, 2002). The 2D resistivity model further agrees with this conclusion (Fig. 13). The figure clearly shows a low resistivity zone (27 ohm-m) flanked on both sides by high resistivity zones (398 ohm-m) at a depth of  $\sim 7.5$  m along profile positions 54 m which defines the position of the azimuthal sounding. Direction of electrical anisotropy is constant along the NW-SE orientation. The direction of the anisotropy plots (Fig. 12) is found to correlate with those deduced in the works of Ibe and Njoku (1999) and Olasehinde and Raji (2007) who found the general directions of faulting in the basement areas to be along NE-SW, NW-SE and N-S.

### CONCLUSION

Electrical anisotropy has been successfully investigated in the Tudun-Wada campus of the Kaduna Polytechnic using the azimuthal Schlumberger and offset Wenner electrode configurations. The coefficient of anisotropy determined for the study area varies from 1.08 in sounding point A to 2.0 in sounding point B. Though these values are departures from the value of 1 for an isotropic homogeneous earth medium, analysis of the relative behaviour of  $R_{D1}$  and  $R_{D2}$  and calculated values of homogeneity index were successfully used to differentiate effects due to heterogeneity from those caused by anisotropy. The azimuthal Schlumberger survey demonstrates the fact that where lateral resistivity variations exists, it will produced elliptical

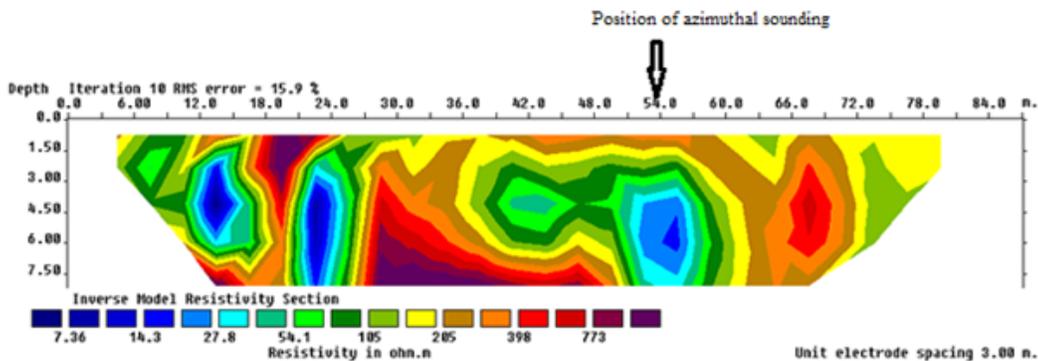


Fig. 13: Electrical image along profile B

shape of the apparent resistivity similar to those recorded on true anisotropic ground. The offset Wenner data related the cause of electrical anisotropy to fracturing beneath the sounding point B at electrode spacing of 15 m, however, the Schlumberger array showed no fracture anisotropy due possibly to the array's low sensitivity to anisotropy at the investigated depths. The result further showed that the offset Wenner array is the most sensitive to fracture anisotropy compare to the Schlumberger array within the depth of investigation in the study area. The direction of electrical anisotropy is predominantly in the N-S and NE-SW directions while the E-S direction is less prominent. The basement rock in the study area are not very competent materials, hence are not good zones for siting disposal wastes and sewage but the materials of the rocks where fracturing and severe weathering occurred (sounding point B) are weak zones and hence can serve as good aquifers.

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