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Full Length Research Paper

Estimation of anisotropic properties of fractures in Presco campus of Ebonyi State University Abakaliki, Nigeria using Azimuthal resistivity survey method

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This study determined and characterized the anisotropic properties of fractures in Presco Campus of Ebonyi State University Nigeria for evaluation of groundwater development and flow within the area. The azimuthal resistivity survey results show that there is significant anisotropy between 0 – 50 m depth and that the fractures at depths of 28.3, 40 and 50 m strike NE-SW, NW-SE and N-S, respectively. Variation of apparent resistivity is strongest between 112.2^0 and 135^0; and between 40 and 50 m depth. Coefficient of Anisotropy, λ, ranges between 1.23 and 1.44 while fracture porosity varies from 0.02 - 0.09 in the area. The coefficient of anisotropy (λ) has been shown to have the same functional form as permeability anisotropy to a first order. Thus, a higher coefficient of anisotropy (λ) implies higher- permeability anisotropy. The results also indicate better permeability and porosity at the depth of 40 and 50 m.

Key words: Electrical anisotropy, fractured shale, porosity, permeability, Abakaliki.

INTRODUCTION

Fractures in rocks are important pathways for ground water flow and contaminant migration. Groundwater flow through a fracture network is strongly influenced by hydraulic anisotropy resulting from the geometry of the fractures. The preferential strike of fracture sets makes rock to be both electrically and hydraulically anisotropic, whereas the variation in the size and opening of fractures causes heterogeneity (Slater et al., 2006). Azimuthal resistivity surveys (ARS) are conducted to determine the principal direction of electrical anisotropy.

The identification and characterization of fractures is important in rocks with low primary (or matrix) porosity because the bulk porosity and permeability are determined mainly by the intensity, orientation, connectivity, aperture and infill of fracture systems (Skyernaa and Jorgenson, 1993). The hydraulic conductivity of fracture systems can range over several orders of magnitude.

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Azimuthal resistivity surveying has been adopted (Leonard-Mayer, 1984; Talor and Fleming, 1988; Ritzi and Andolsek, 1992; Skyernaa and Jorgensen, 1993; Hagrey, 1994; Boadu et al., 2005; Slater et al., 2006) as a technique for determining the principal directions of electrical anisotropy and hence, hydraulic conductivity using the analogy between Ohm's and Darcy's Law can be derived. Typically, any observed change in apparent resistivity with azimuth is interpreted as invocative of anisotropy (generally fracture anisotropy). It is often assumed that the principal directions of hydraulically conductive fracture measured from electrical anisotropy may be inferred from the measured electrical anisotropy (apparent resistivity (ρa) as a function of azimuth and the strike of the fracture), since both current flow and groundwater are channeled through fractures in the rock. ARS details from electrical anisotropy, sometimes, may not be a proof for hydraulically active fractures as other features example; clay mineral lining bedrock fractures can also generate electrical anisotropy. Therefore, ARS can fail when structural features other than fractures cause the subsurface to exhibit anisotropy and or heterogeneity. This has resulted in ambiguity in the geologic

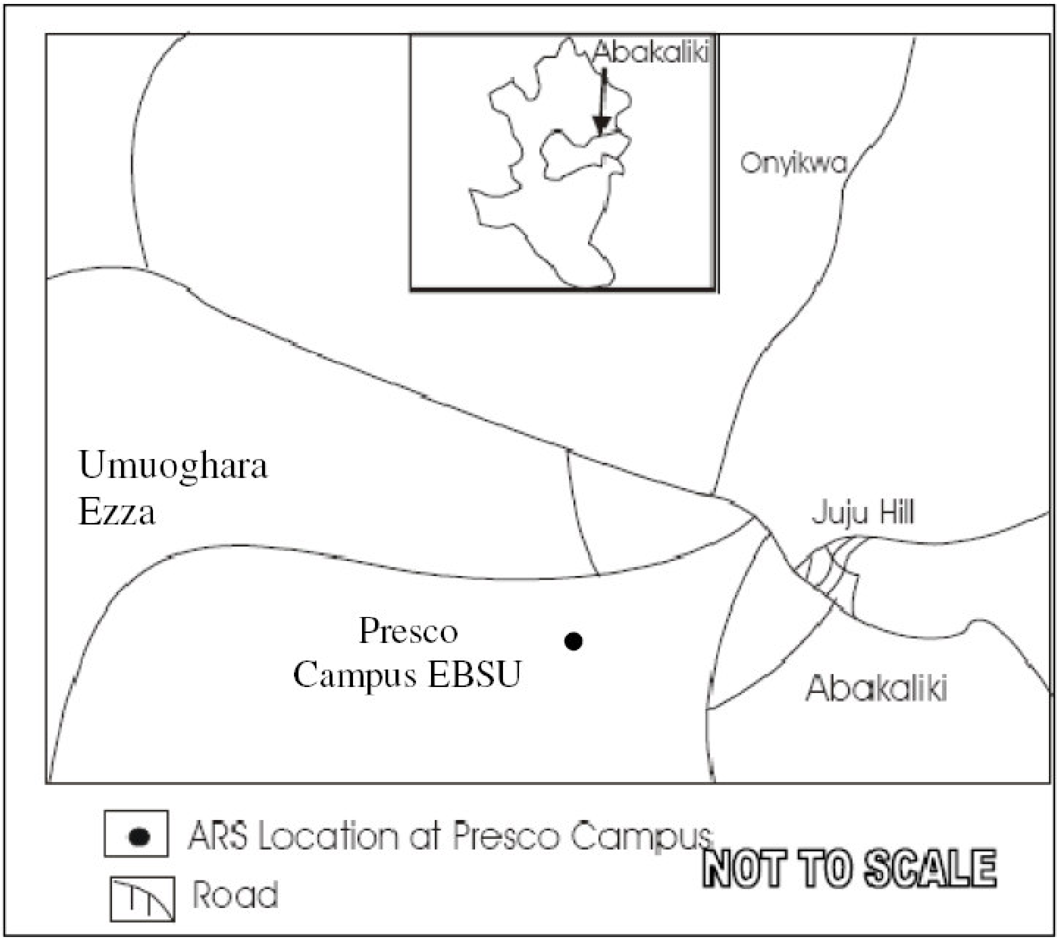

Figure 1. Azimuthal Resistivity Survey (ARS) location in Presco Campus of Ebonyi State University Abakaliki

geologic interpretation of several previous ARS investigations (Taylor et al., 1988; Watson and Barker, 1999). This study presents and characterizes fractured shale anisotropy in Presco campus of Ebonyi State University using Azimuthal resistivity measurements.

The study area (Figure 1) lies within the Albian Asu River group and consist mainly of rather poorly bedded shales, occasionally sandy, splintery metamorphosed mudstones. Lenses of sandstone and sandy limestone are highly jointed and fractured. The Albian shale Formation in the study area are intruded by younger intrusive. These are the earliest known sediments and lie unconformable on the Basement (Burke et al., 1972; Reyment, 1965). The intrusive bodies in combination with numerous faults and joint systems have created fractures and secondary porosity in the study area.

Tectonism in Southern Nigeria started in Early Cretaceous with the separation of Africa from South America (Hoque, 1977) and Murat (1972) recognized that the Middle Albian Tectonic Phase was responsible for the NE-SW faulting that produced the Abakaliki- Benue Rift (anticlinoria).

There is evidence of minor volcanic activity during various sedimentary cycles, accompanied sometimes with lead-zinc mineralization. Lead-zinc mineralizations however are confined to the first sedimentary cycle.

METHODOLOGY

A DC- resistivity survey using the square array method was conducted in a manner similar to that of traditional collinear array. The location of measurements was assigned to the centerpoint of the square. The array size (A) is the length of the side of the square. The array was expanded symmetrically about the centerpoint, in increments of $A(2)^{1/2}$ (Habberjam and Watkins, 1967), so that the sounding can be interpreted as a function of depth.

Resistivity Earth model 500 was used for the field measurements. In designing the square electrode array, different electrodes spacing of 5, 7.1, 10, 14.1, 20.0, 28.3, 40.0 and 50 m form the side of the array. Two Azimuthal resistivity surveys were carried in the study. The electrode positions were rotated in increments of 22.5° and 45° about a central point as shown in Figures 3a and 3b. An initial array test selected square array with a 22.5° Azimuth step as a suitable array owing to the possession of the following properties:

(1) Higher sensitivity: The step size is confirmed similar to a linear array but sensitivity is higher than dipole array because two MN lines are at 90° differences.
(2) Completely identical signals in both MN lines. This property

Table 1. ARS at Presco campus, Ebonyi State University, Abakaliki Azimuthal apparent resistivity in ohm meter (Ωm).

A(m)	K	Mean	0°	22.5°	45.0°	67.5°	90°	112.5°	135°	157.5°
5.0	53.6	1103.8	825	563	1,206	1,734	187	1011	1,936	1,368
7.1	75.8	1139.7	838	269	1,089	1,776	441	1,137	2431	1,137
10.1	107.3	2555.8	9,687	249	1,495	309	1,642	1,113	4,721	1232
14.1	151.7	5825.3	9,956	2,999	3070	3,659	4,042	4320	3,898	3,122
28.3	214.5	2053.0	2,251	1,842	2,541	2,940	1,6830	2,340	1,400	1,427
40.0	429.0	1961.6	1,420	2,146	1,574	1,923	2,950	2,464	1,680	1,536
50.0	536.3	2127.5	402	1,734	1,995	2,869	2,212	4,674	1,009	-

Table 2. Characteristics fracture parameter from ARS.

Location and coordinates	A-spacing (m)	Strike direction	Coefficient of anisotropy (λ)	Mean apparent resistivity (Ωm)	ϕ_f from ARS
Presco EBSU Campus	28.3	22.5°NE-SW	1.23	2053.0	0.02
N06°19'13.6''	40.0	157.5°NW-SE	1.44	1961.6	0.09
E008°4'52.5''	50.0	0°N-S	1.43	2127.5	0.08

above anisotropic media allow to measure signs only in one line, hence measurements in two MN lines help to distinguish homogeneous medium from anisotropic one by taking into account the difference of two signals.
(3) Field survey convenience.

Four Azimuthal resistivity surveys were carried out at different locations using the Earth model Res 500. The square array was expanded about a center point, increments of A $(2)^{1/2}$ (Habberjam and Watkins, 1967), so the sounding s, can be interpreted as a function of depth as indicated from the nature of the array sizes. The apparent resistivity (ρa) and the geometric factor (k) for the survey as shown in Table 1 were calculated using equations 1 and 2 respectively.

$$\rho_a = \frac{k\Delta v}{I} \quad (1)$$

$$k = \frac{2\pi A}{2-(2)^{1/2}} \quad (2)$$

Where:
I = the current in amperes and
Δv = the voltage change in volts and the resistance is the ration of the voltage to the current.

To minimize possible overburden effects, the data were analyzed by plotting the apparent resistivity against Azimuths of 28.3, 40.0 and 50.0 m A - spacing.

Fracture porosity

Secondary porosity or fracture porosities associated with tectonic fracturing of rocks were estimated using the expression derived by Lane et al. (1995) equation 3;

$$\phi_f = \frac{3.41\times10^4(N-1)(N^2-1)}{N^2C(\rho_{a\max}-\rho_{a\min})} \quad (3)$$

$$N = [(1+\lambda^2-1)\sin^2\alpha]^{1/2} \quad (4)$$

$$\lambda = (\rho_{aT}/\rho_{aL})^{1/2} \quad (5)$$

Where:
Φ = the strike of the fractures;
Φ_f = fracture porosity;
N = the vertical anisotropy related to the co-efficient of anisotropy λ and dip of the bedding plane α as shown in equation (4);
$\rho_{a\max}$ = Maximum apparent resistivity;
$\rho_{a\min}$ = Minimum apparent resistivity;
ρ_T = Apparent resistivity transverse to the direction of the fracturing;
ρ_L = Apparent resistivity longitudinal to the direction of the fracturing; and
C = Specific conductance of ground water in microsiemens per centimeter (µs/cm).

In this study, the specific conductance of groundwater in the Abakaliki shale averaged 736 µs/cm (Eze, 2008).

Table 2 shows the characteristics fracture parameters at each site obtained from analysis of Azimuthal resistivity data obtained from the study area.

RESULTS AND DISCUSSION

The results of apparent resistivity obtained at different azimuths and depths are presented in the tables.
Table 2 shows the different fracture parameters obtained from the Azimuthal resistivity measurements. Petrophysical properties of the fractured shale are better developed at depth of 40 to 50 m as shown in Table 2.

The presence of aligned vertical or sub-vertical fractures causes a fractured rock mass to exhibit Azimuthal anisotropic behavior. In using ARS, any observed change in apparent resistivity (ρ_a) was interpreted as an indication

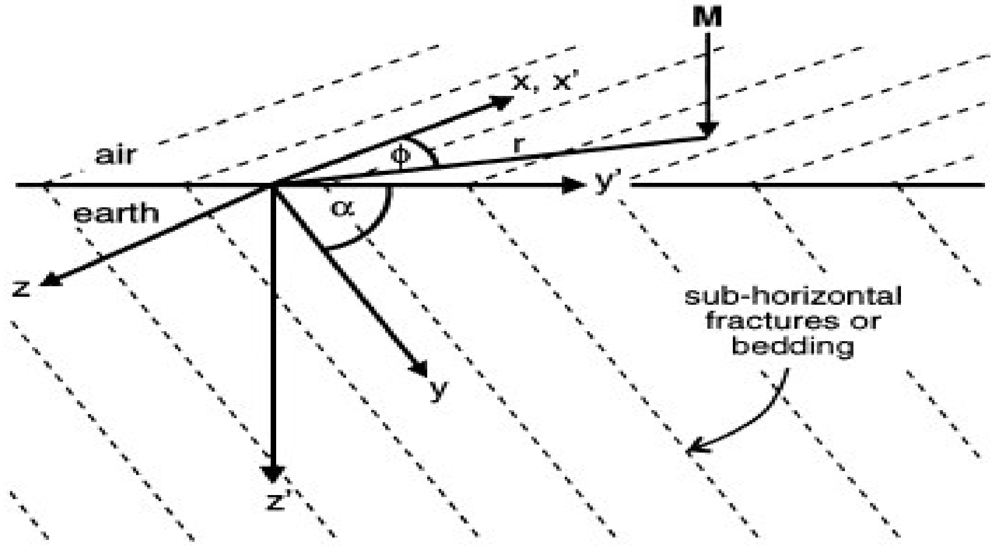

Figure 2a. Coordinate system defining a generalized two-dimensional anisotropic half space, xy = plane of stratification; x'y' = air-earth boundary; α = dip of the bed; ϕ = angle made by the point of observation with the strike direction (Bhattacharya et al., 1968).

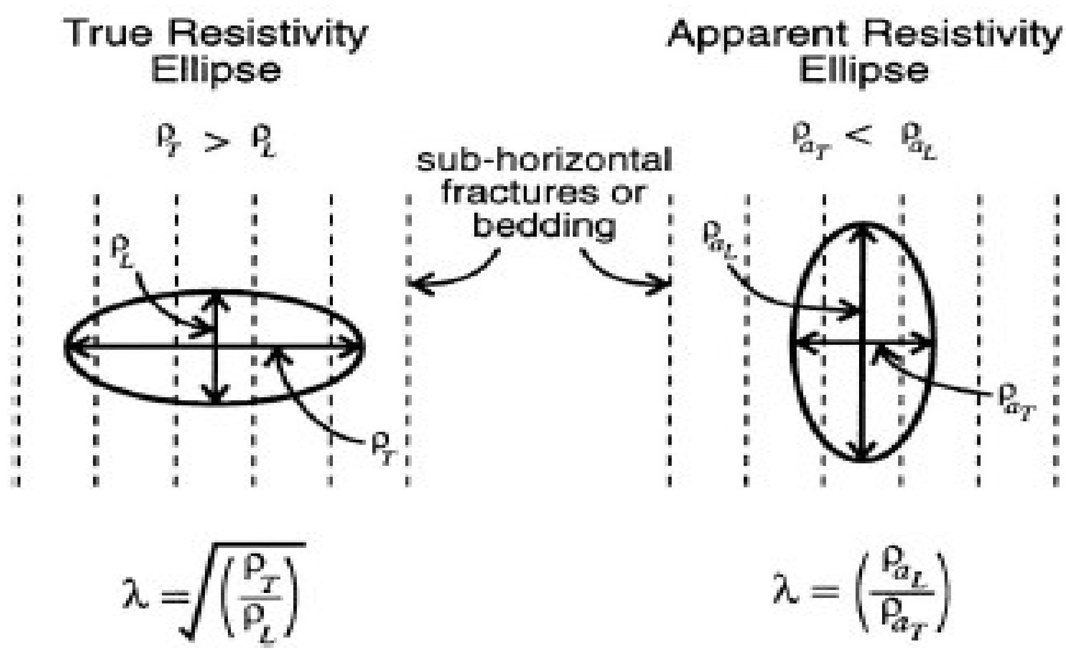

Figure 2b. Resistivity Ellipse- Paradox of anisotropy (Watson and Barker 1999- Geophysics, 64(3): 739-745).

of fracture anisotropy.

The direction of maximum apparent resistivity measured by the square array will be perpendicular to fracture strike Figure 2a. This is a function of the cosine term in the denominator of equation 7. This is a consequence of the "paradox of anisotropy"(Keller and Frischknecht, 1966) Figure 2b.

The data collected show a significant variation of apparent resistivity for different Azimuthal array Figures 3a and 3b orientation for all A-spacing. Apparent resistivity data collected is shown in Table 1. The data from the longest arrays were analyzed to minimize possible over burden effects. The apparent resistivity was plotted against the Azimuth (Figures 4). In each plot, a single

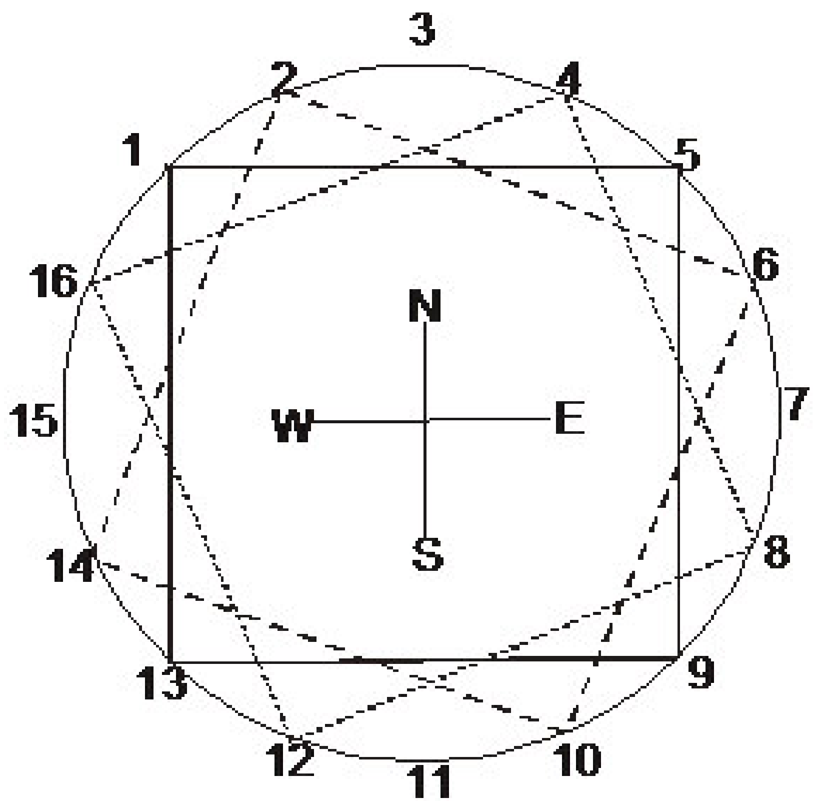

Figure 3a. Electrode arrangement for the square–array Azimuthal survey with an increment of 22.5^0 about the centerpoint (Boadu et al., 2005).

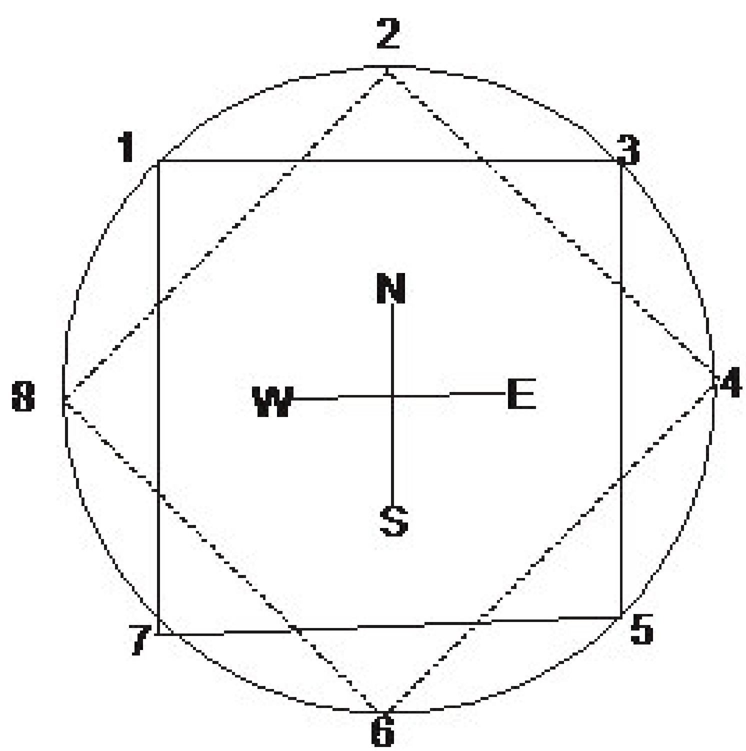

Figure 3b. Electrode arrangement for the square – array Azimuthal survey with an increment of 45^0 about the centerpoint (Boadu et al., 2005).

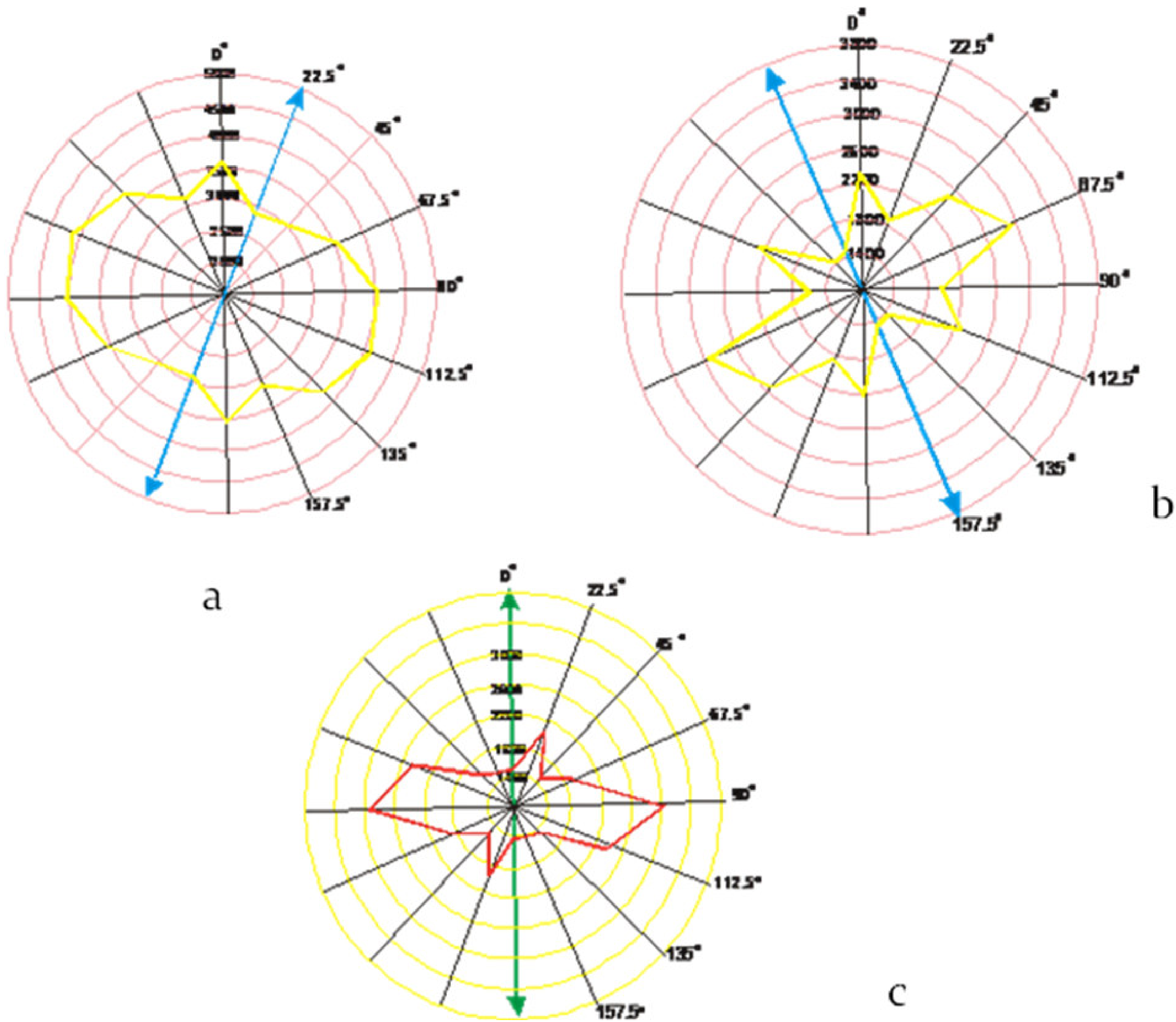

Figure 4. Polar plots of apparent resistivity against Azimuth at Presco Campus EBSU. (a) A=28.3 m, (b) A=40.0 m (c) A=50.0 m.

single dominant fracture orientation was observed. The graphical interpreted fracture strikes obtain from the resistivity measurement is given in Figure 4. Variation of apparent resistivity is strongest between 112.2° and 135°; and between 40 and 50 m depth as shown in Figure 5.

The coefficient of anisotropy (λ) has been shown to have the same functional form as permeability anisotrop to a first order (Bespolov et al., 2002). Thus, a higher coefficient of anisotropy (λ) implies higher- permeability anisotropy.

Conclusion

Azimuthal apparent resistivity measurements are potentially a powerful method for characterizing fractured rock since they measure parameters, which cannot be obtained from traditional profile measurements. Field Azimuthal resistively surveys and geologic field mapping conducted in Abakaliki was aimed at characterizing the subsurface fractured rock mass. Fracture parameters obtained from the field measurements included fracture orientation, coefficient of anisotropy, mean resistively and

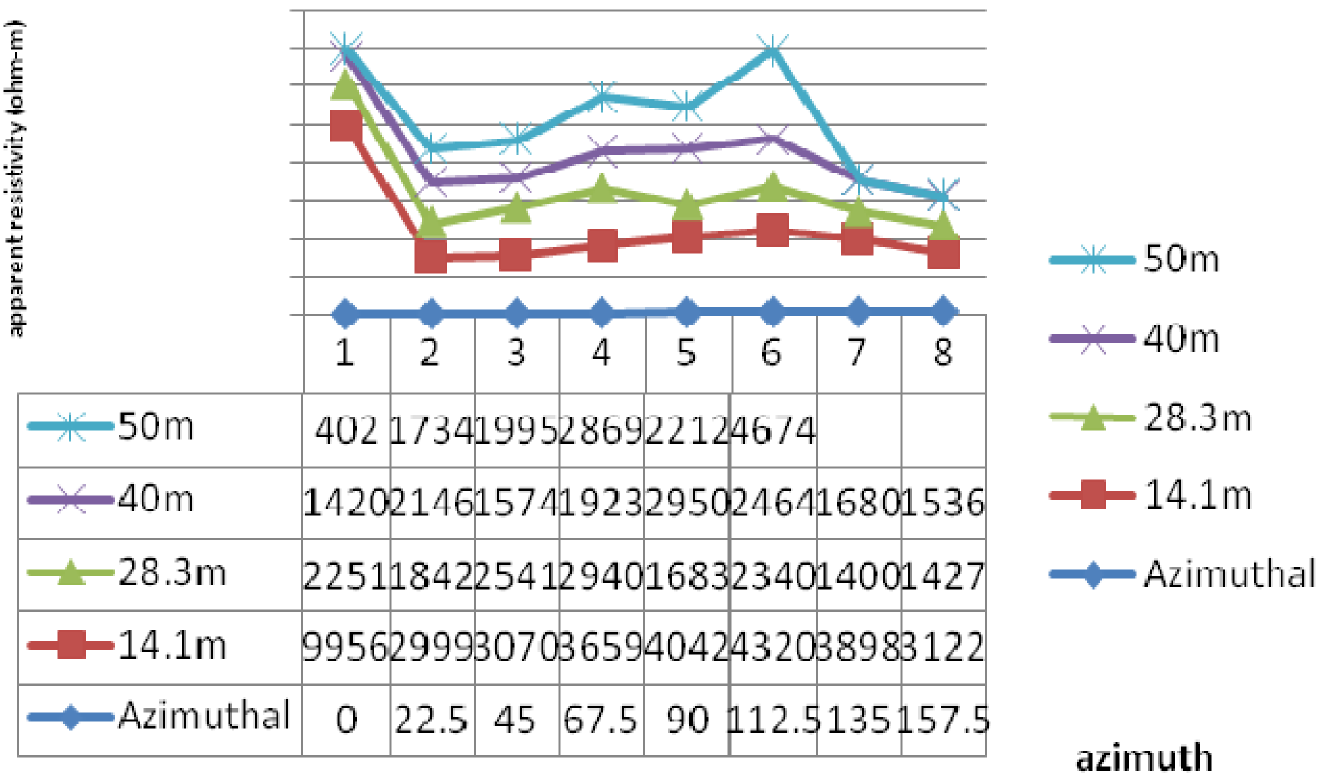

Figure 5. Variation in apparent resistivity with azimuth and depth.

fractures porosity or intensity. These fracture parameters are useful in assessing the intensity of fracturing and the permeability of the fractured rock mass. These parameters are useful in making preliminary inference on the degree of fracturing and permeability of the rock mass. The following conclusions have been deduced from this study:

(1) The Azimuthal resistivity survey results show that there is significant anisotropy between 0 - 50 m depth and that the fractures at depths of 28.3, 40 and 50 m strike NE-SW, NW-SE and N-S.
(2) The analysis of the resistivity data indicates that the fracture porosity within the study area range from 2 to 9% and that the coefficients of anisotropy range from 1.23 to 1.44 as shown in Table 2.
(3) The Azimuthal square array DC-resistivity method is more sensitive to fractured shale anisotropy in the area than the more commonly used schlumberger and Wenner arrays. The square away method requires less surface area than an equivalent survey using Schlumberger or Wenner array.

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