COMPARATIVE VES STUDIES FOR THE DETERMINATION OF FRACTURE ORIENTATION USING AZIMUTHAL SQUARE ARRAY AND SCHLUMBERGER ARRAY DATA IN AWI WITHIN THE OBAN MASSIF, S.E. NIGERIA

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Abstract

Azimuthal Resistivity survey (ARS) was conducted using square array and Schlumberger array configuration to determine fracture strike orientation at selected sites in Awi, located within the Oban Massif, Southeastern Nigeria. A total of six (6) sites were surveyed within the study area. Square-array measurement was carried out at four (4) sites while Schlumberger array measurement was carried out at two (2) sites, using ABEM SAS 300 Instrument and its accessories. The result obtained from this study showed a N-E and N-W orientation of fractured rock mass within Awi with direction ranging from 225 to 345, for square array and 90^0 to 285^0 for Schlumberger array. The coefficient of anisotropy estimated from the field data was of range 1.09 to 1.60. These results were in good agreement with the known predictions of fracture orientation in the geology map of the area. The findings in this work using azimuthal Square array has shown that it is a very reliable method in the determination of fracture orientation in basement terrains.

Keywords: *Square array, fracture, azimuthal, resistivity and orientation*

Introduction

The knowledge of fracture orientation and location of fracture zone is very important in fluid flow modeling and contaminant transport. In a fractured rock mass, the preferential direction for bulk fluid flow undoubtedly lies along the major fracture directions. While fractures contribute to the hydraulic or transport properties of a fractured rock mass, quantification of a fracture system still remains a formidable task. The drilling of test wells for fluid flow studies and the determination of hydraulic properties of subsurface rocks is an expensive method. Surface geophysical methods had been proven to be a rapid and inexpensive complement to drilling for determining the locations and orientation of fractured zones in bedrock.

Two methods of direct current (dc) resistivity, azimuthal square-array and Azimuthal Schlumberger survey method were used at six (6) locations in Awi to determine the orientation of saturated fracture zone in the crystalline bedrock.

Fracture orientation determination using Azimuthal square array as discussed in this paper has rarely been used in Nigeria and surprisingly has not been widely used even in other parts of the world. The study attempts to determine the existence and particularly the orientation of fractures and correlate the determined fracture orientation with those already mapped by field geologists.

Geology of Study Area

Awi is located within Oban Massif, South Eastern Nigeria. It is overlain by Cretaceous - Tertiary sediment of the Calabar flank. The Oban Massif occupies about 10,000km^2, mappable rock units in this area which include metamorphic rock units such as phyllites, schists, gneisses and amphibolite. These rocks are intruded by pegmatites, granites, grandiorites diorites, tonalites, monzonites and dolorites (Ekwueme, 1990).

The location and geologic map of Oban Massif is shown in figure 1a and 1b. The area has a complex terrain and the differentiation of the rock types had remained difficult. One of this difficulty stems from the location of the Oban Massif which is in the thick equatorial rain forest highly populated by wild life. Secondly, rock outcrops in the area are generally intensely weathered and this makes it difficult to obtain fresh rock for geologic studies. The oldest rock in the Oban Massif is the banded gneisses and dolorite is the youngest.

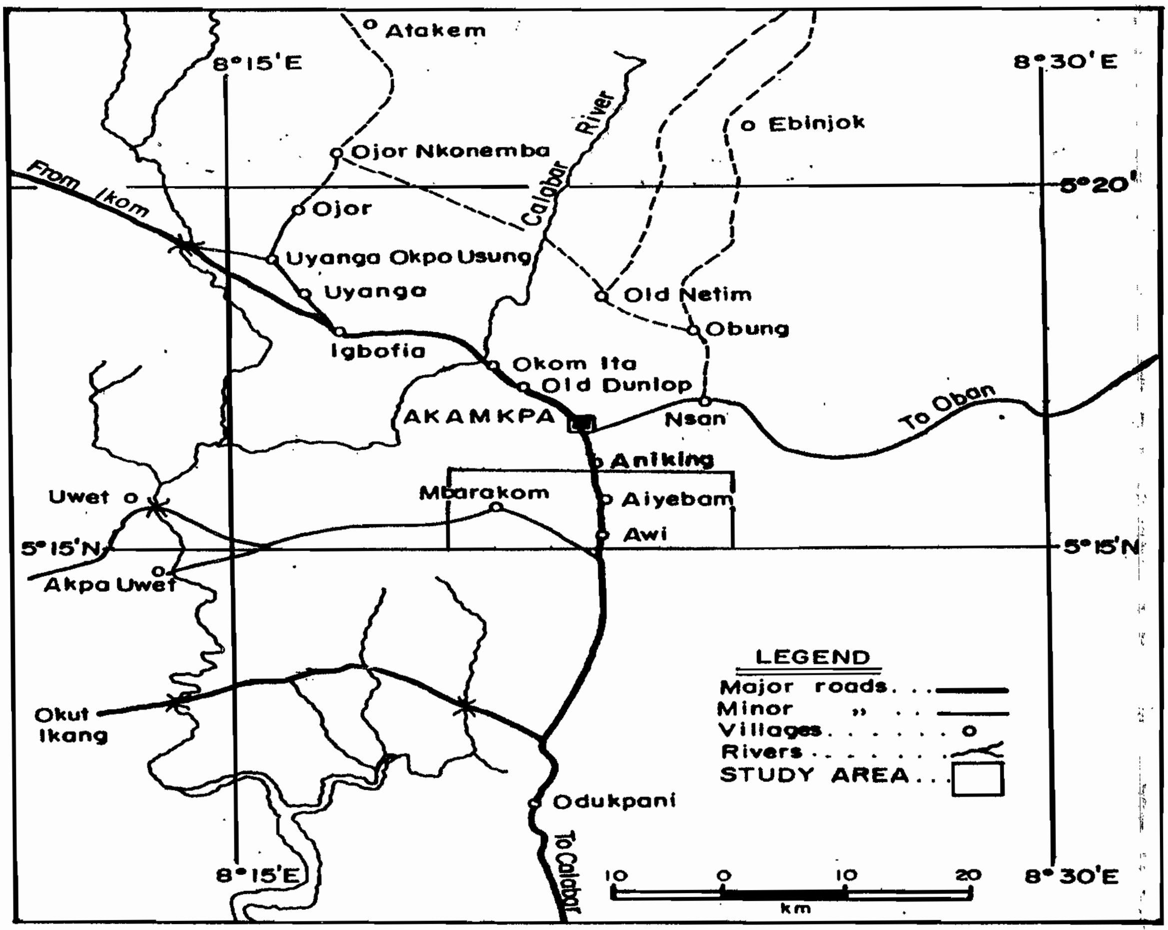


Fig. 1a: Location map of study area

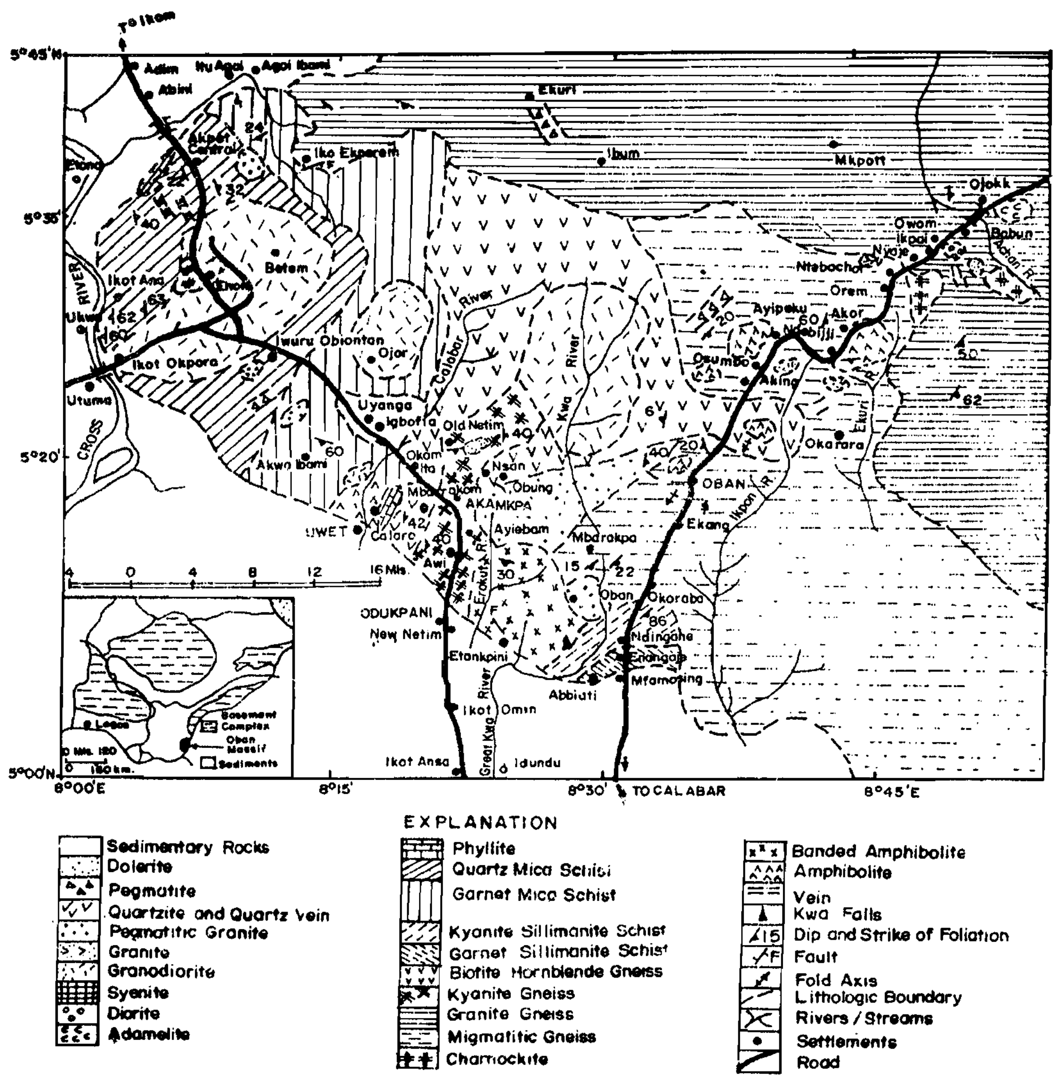


Fig. 1b: Geologic map of Oban massif southeastern Nigeria

Field Method and Measurement

Dc resistivity soundings measure changes in apparent resistivity and in this case with respect to Azimuth, using square - array and Schlumberger array. Azimuthal square array method is about twice as sensitive to anisotropy as are linear arrays. For square-array, the location of measurement point is the centre point of the square while for azimuthal Schlumberger; the measurement point is the centre of the potential electrode.

For this study, an array size of 42.4m, 56.6m and 70.7m was used and each square was rotated in 15° increments about the centre point for a total of 180°. Field arrangement for azimuthal square array data collection is as shown in Fig. 3. Azimuthal Schlumberger array data collection was also carried out and data collected at an incremental rate of 30° about the same centre point for a total of 180°. This was done to compare square array result with collinear result. A total of six (6) sites were surveyed within the study area. Azimuthal square array and Schlumberger array equipment consist of mainly steel electrodes, electrode - switchers (if any) and connecting wire and ABEM SAS 300.

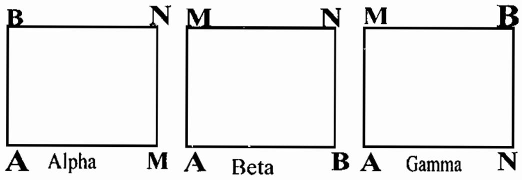
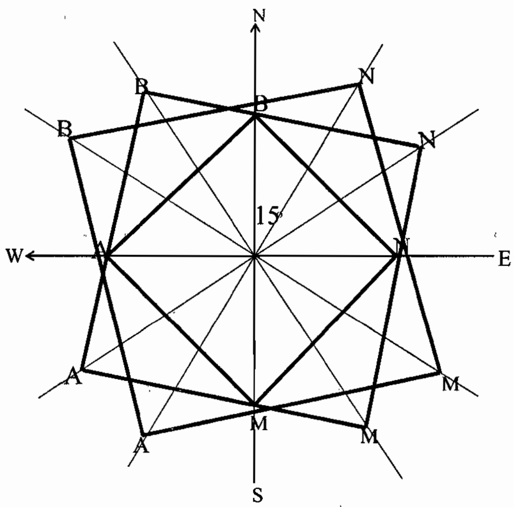


Fig. 2: Electrode configurations for square array data collection

Other accessories include GPS, theodolite and measuring tapes.

For each square, three measurements are made, two perpendicular measurements (alpha α and beta, β) and one diagonal measurement (gamma,γ) Fig. 2.



AB = current electrodes
MN = potential electrodes

Fig. 3: Field arrangement for azimuthal square array data collection

The α and β measurements provide information on the directional variation of the subsurface apparent resistivity (ρ_a). The azimuthal orientation of the α and β measurements is that of the line connecting the current electrodes. The γ measurement serves as a check on accuracy of the α and β measurement.

In an isotropic medium,
$\rho_{a\alpha} = \rho_{a\beta}$, therefore $\rho_{a\gamma} = 0$ (1)

and in a homogeneous anisotropic medium, $\rho_{a\gamma} = \rho_{a\alpha} - \rho_{a\beta}$ (2)

where ρ_a = apparent resistivity, in Ohm - meters.

Conventionally, apparent resistivity in dc resistivity survey is determined using the equation.

$$\rho_a = \frac{K \Delta V}{I} \quad (3)$$

where K = geometric factor, I = current in ampere for square array of size equal to A,(Habberjam and Watkins, 1967)

$$k = \frac{2\pi A}{2-\sqrt{2}} \quad (4)$$

Data Analysis

Azimuthal resistivity survey (ARS) have been adopted by (Taylor and Fleming, 1988, Ritzi and Andolsek, 1992; al Hagrey, 1994) as a technique for determining the principal fracture direction. In using (ARS), any observed change in apparent resistivity (ρ_a) is interpreted as an indication of fracture anisotropy. However, it is important to note that azimuthal variation in ρ_a might also be produced by the presence of a dipping bed or inhomogeneities or lateral changes in ρ_a (Metias and Habberjam, (1986), Watson and Baker, 1999, Busby, 2000, Matias 2002.

For homogeneous anisotropic earth, the variation of apparent resistivity with square-array orientation is as given by Habberjam (1972) thus

$$\rho_a = 0.7\rho_m\{{}^2/_P - {}^1/_Q - {}^1/_R\} \quad (5)$$

where $P = [1 + (N^2-1)\cos^2\varphi]^{½}$

$Q = [2 + (N^2-1)(1+\sin 2\varphi)]^{½}$

$R = [2 + (N^2-1)(1-\sin 2\varphi)]^{½}$

ρ_m is mean resistivity of the fractured rock. φ is the strike of the fracture, N is the effective vertical anisotropy and is related to the coefficient of anisotropy λ and the dip of the bedding plane (α) thus

$$N = (1 + (\lambda^2 - 1)\sin^2\alpha)^{1/2} \quad (6)$$

The parameters λ and ρ_m are diagnostics of an anisotropic medium and are defined as

$$\lambda = (\rho_{at}/\rho_{al})^{½} \quad (7)$$

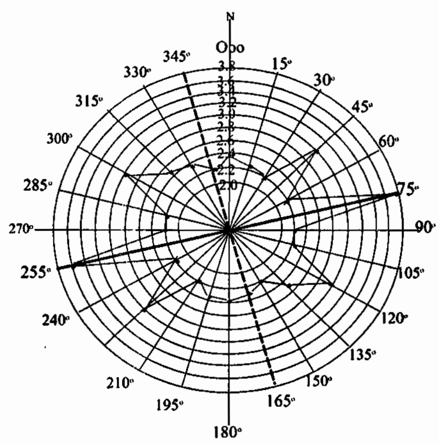
and

$$\rho_m = (\rho_{at}\,\rho_{al})^{½} \quad (8)$$

where ρ_{at} and ρ_{al} are, respectively apparent resistivity transverse and longitudinal to the direction of fracturing.

Determination of Fracture Strike

Fracture strike orientation can be determined graphically or analytically. In this work, the graphical interpretation mode is used. The value of apparent resistivity measurement for each square orientation was plotted against the azimuth for that square (see Fig. 4).



200 Line of equal apparent resistivity in ohms meters Interpreted

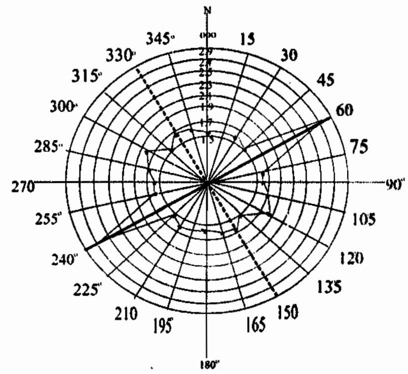
-------- Primary fracture strike direction

——— Direction of maximum apparent resistivity

* Data point showing apparent resisitivity at indicatd azimuthal directions.

Ooo Compass azimuth

Fig. 4a: Square array apparent resistivity plot against azimuth for a=42.m at AW I.



200 Line of equal apparent resistivity in ohms meters

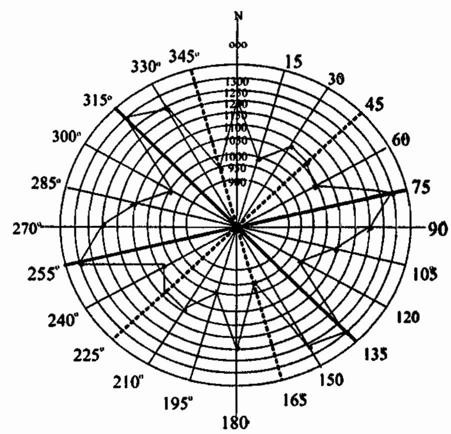
-------- Interpreted primary fracture strike direction

——— Direction of maximum apparent resistivity

* Data point showing apparent resisitivity at indicated azimuthal directions.

ooo Compass azimuth

Fig. 4b: Square array apparent resistivity plot against azimuth for a=56.56m at AW II.



50 Line of equal apparent resistivity in ohms meters Interpreted

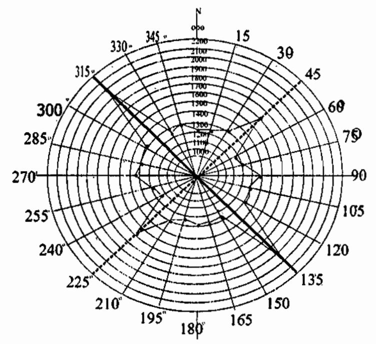
-------- primary fracture strike direction

——— Direction of maximum apparent resistivity

* Data point showing apparent resisitivity at indicated azimuthal directions.

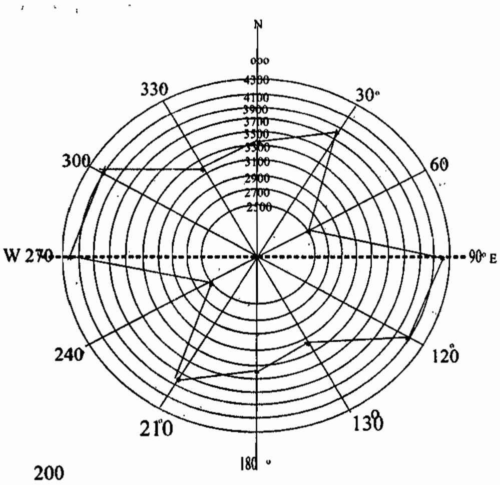
ooo Compass azimuth

Fig. 4c: Square array apparent resistivity plot against azimuth for a =70.7m at AW IV.



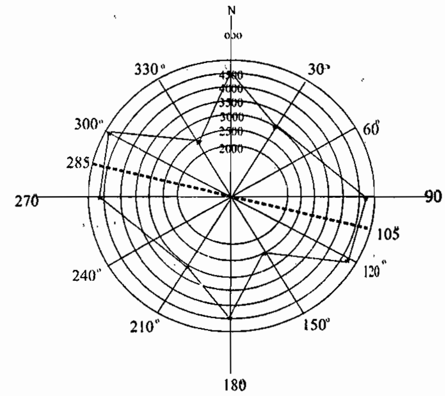
100 Line of equal apparent resistivity in ohms meters Interpreted
-------- primary fracture strike direction
——— Direction of maximum apparent resistivity
* Data point showing apparent resisitivity at indicated azimuthal directions.
000 Compass azimuth

Fig. 4d: Square array apparent resistivity plot against azimuth for a = 56.6m at AW III.



200 Line of equal apparent resistivity in ohms meters
-------- Interpreted primary fracture strike direction and direction of maximum apparent resistivity
* Data point showing apparent resisitivity at indicated azimuthal directions.
000 Compass azimuth

Fig. 4e: Azimuthal schilumbergr apparent resistivity plot against azimuth at AW I for AB/2=100m.



500 Line of equal apparent resistivity in ohms meters
-------- Interpreted primary fracture strike direction and direction of maximum apparent resistivity
* Data point showing apparent resisitivity at indicated azimuthal directions.
000 Compass azimuth

Fig. 4f: Azimuthal schilumbergr apparent resistivity plot against azimuth at AW II for AB/2=120m.

Similarly, the apparent resistivity for Schlumberger array was plotted against the azimuth for a AB/2 of 100m and 120m respectively, using Taylor and Fleming's method (1988).

From the rosette diagrams of figure 4 according to Habberjam (1975) the principal fracture strike direction for azimuthal square-array plot is perpendicular to the direction of maximum apparent resistivity. For azimuthal Schlumberger plot, the principal fracture strike direction is parallel to the direction of maximum apparent resistivity.

Results and Discussion

Data collected at Awi shows a significant variation of apparent resistivity for different azimuthal array orientations for all A-spacings. A-spacing of 42.4m, 56.6m and 70.7m was used for the survey and analyzed to minimize possible overburden effects.

The general trend of the fracture strike in three of the locations AW I, AW II and AW III shows a North- East orientation with an exception of AW IV which had a North - West orientation (Table 1). At AW 1, the maximum apparent resistivity measured is parallel to 075°, with a graphical interpretation of primary fracture strike of North 345° East.

At AW II, the maximum apparent resistivity measured is parallel to 060°, with fracture strike of North 330° East. At AW IV, maximum apparent resistivities measured are parallel to 075° and 135° an indication of multiple strikes, with orientation of North 345° East and North 225° West. At AW III, the maximum apparent resistivity measured is parallel to 135° with fracture strike of North 225° West.

The coefficient of anisotropy obtained for the study area was in the range of 1.09 to 1.60.

The strike orientation determined geophysically in this work is in agreement with work carried out geologically by Udoh (1988) and Ukaegbu and Oti (2005). The results obtained using Azimuthal Schlumberger array at the same measurement point as square array show maximum apparent resistivity measured at AW 1 parallel to 090° indicating the strike orientation in an East-west direction at that location. Similarly, at AW I using azimuthal Schlumberger, the maximum apparent resistivity was obtained to be parallel to 105° indicating a strike orientation of North 285° East in that location.

The summary of graphically interpreted fracture strike obtained and other fracture parameters are given in Table 1 and 2 for square array and schlumberger array respectively.

Table1: Summary of fracture parameter obtained using azimuthal square array.

Site	A spacing (m)	Coefficient of anisotropy (λ)	Major strike direction	Mean apparent resistivity (Ohm-meter)
AW I	42.4	1.25	North 345° East	2879.4
AW II	56.6	1.32	North 330° East	213.6
AW III	56.6	1.21	North 225° West	1643.2
AW IV	70.7	1.60	North 345° East	1002.7
		1.09	North 225° West	1170.2

Table 2: Summary of fracture parameter obtained using azimuthal Schlumberger array.

Site	AB/2 (m)	Apparent anisotropy λ_a	Major strike direction	Mean apparent resistivity (Ohm-meter)
AW I	100.0	1.24	East-West	3778.9
AW II	120.0	1.28	North 285° East	3995.5

Comparison of Square Array and Collinear Array

The electrode spacing to be used for the study must be large with respect to the fracture spacing (Taylor, (1982). The potential to current electrode ratio spacing of 1:1 for square-array, 1:3 for Wenner array and less than 1:10 for Schlumberger array makes the square-array (with the largest electrode-spacing ratio) satisfy the above condition when the array is expanded. The higher apparent anisotropy measured by the square array in AW I and AW II as compare to Schlumberger array in the same location is an advantage, because the anisotropy is less likely to be obscured by heterogeneities in bedrock or overburden, bedrock relief, cultural noise, electrode placement errors, or other sources of noise.

The square array geometry is more compact than Schlumberger or Wenner arrays for azimuthal surveys. The square array requires 65 percent less surface area than the equivalent collinear arrays. This is an advantage in an area with significant lateral heterogeneities or when the area available to conduct a survey is limited.

Conclusion

Azimuthal resistivity survey (ARS) was conducted at six (6) locations in Awi, within the Oban Massif in SE-Nigeria in order to determine the fracture strike orientation. The fracture parameters obtained from the field measurements included fracture orientation, coefficient of anisotropy and mean resistivity. Analysis of azimuthal square-array resistivity data collected indicate that the fracture orientations within the study area are (N-E) and (N-W), with coefficient of anisotropy ranging from 1.21 to 1.60. This study shows good agreement with estimated fracture orientation strikes denoted in the existing geology and basement fracture maps of the study area. The 1:1 ratio of potential to current electrode spacing in square array makes it very sensitive to rock anisotropy detection and above all, it requires less surface Area for survey as compared to Schlumberger array.

The result is very useful and shows that in the absence of rock exposures, a non invasive geophysical method (dc resistivity) may be useful in obtaining valuable information about a subsurface fractured rock mass.

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