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DC-Resistivity Estimation of Second Porosity and Anisotropy Using Azimuthal Resistivity Surveys: A Case Study of Part of Oban Massif and Obudu Plateau, Southeastern, Nigeria

[1]A.M. George, [1]A.A. Okiwelu and [2]D.A. Obi

[1]Geophysics Unit, Department of Physics, University of Calabar, Calabar, Nigeria
[2]Department of Geology, University of Calabar, Calabar, Nigeria

Abstract: Dc resistivity method was employed for the estimation of secondary porosity using azimuthal resistivity survey (ARS) data collected at part of Oban Massif and Obudu Plateau, Southeastern Nigeria. Data were collected using the azimuthal square and the crossed square array configurations. The study was conducted to estimate the fracture porosity and coefficient of anisotropy of the fractured rock mass at the selected sites. A total of nine (9) sites, four (4) within the Obudu Plateau and five (5) within the Oban Massif was surveyed, using ABEM SAS 300 equipment and its accessories. Squares of sizes 42.4m, 56.6m, 70.7m and 84.9m were used for the study. The results obtained show a range in secondary porosity of 0.001 to 0.02 at Oban Massif with range of anisotropy of 1.03 to 1.40. At the Obudu Plateau, the investigation showed a porosity range of 0.004 to 0.009 and the coefficient of anisotropy of 1.03 to 1.20. Square array profiling was also carried out within the Oban Massif in order to determine specific fracture locations. Profile length of 240m was used and a plot of apparent resisitivity and porosity estimate against the square array centre showed the presence of low apparent resistivity and high porosity at 60m and 240m respectively along the profile indicating the presence of fracture at the 60m and 240m points underneath. Results from this study are very significant in assessing hydraulic properties of the fracture rock mass and therefore minimize the problem of locating portable ground water in the geological provinces.

Key words: Porosity % Anisotropy % Resisitivity % Azimuthal and Oban massif

INTRODUCTION

Groundwater is considered very essential for life on the Planet Earth. This being the case, the location of groundwater aquifer is considered very important because of its benefit to humans living within an area. Groundwater aquifer types vary from place to place depending on the geological settings. In basement area groundwater aquifer is believed to exist within the overburden, joints or fracture zones. It is on the basis of this that this study is carried out to identify the fractured zones and determine the zones parameters. In the Obudu and Oban massif there are scanty geophysical data for ground water study. Most of the bore holes drilled in the early eighties and late nineties in the study area are now dry holes. It therefore, becomes imperative to carry out geophysical site investigation for accurate location and sustainable of ground water aquifer. This study, therefore, will be very significant to minimize the problem of portable water in the two geological provinces.

DC-resistivity methods have been successfully used by a number of investigators [1-12]. The square array and crossed square array was tested at sites within Obudu Plateau and Oban Massif. This research report describes the square - array and crossed square dc-resistivity method and outlines a simplified method of data analysis to determine secondary porosity of the fractured zone. The Obudu Plateau, flanked in the Northeastern and Southeastern by the elongated Benue Trough and on the Southeast by the Cameroon Volcanic line, is part of Precambrian Basement complex [13-15] representing the Western prolongation of the Bamenda massif of the Cameroon into Southeastern Nigeria [16-18].

Corresponding Author: A.A. Okiwelu, Geophysics Unit, Department of Physics, University of Calabar, Calabar, Nigeria.
E-mail: okiwelu2000@yahoo.com.

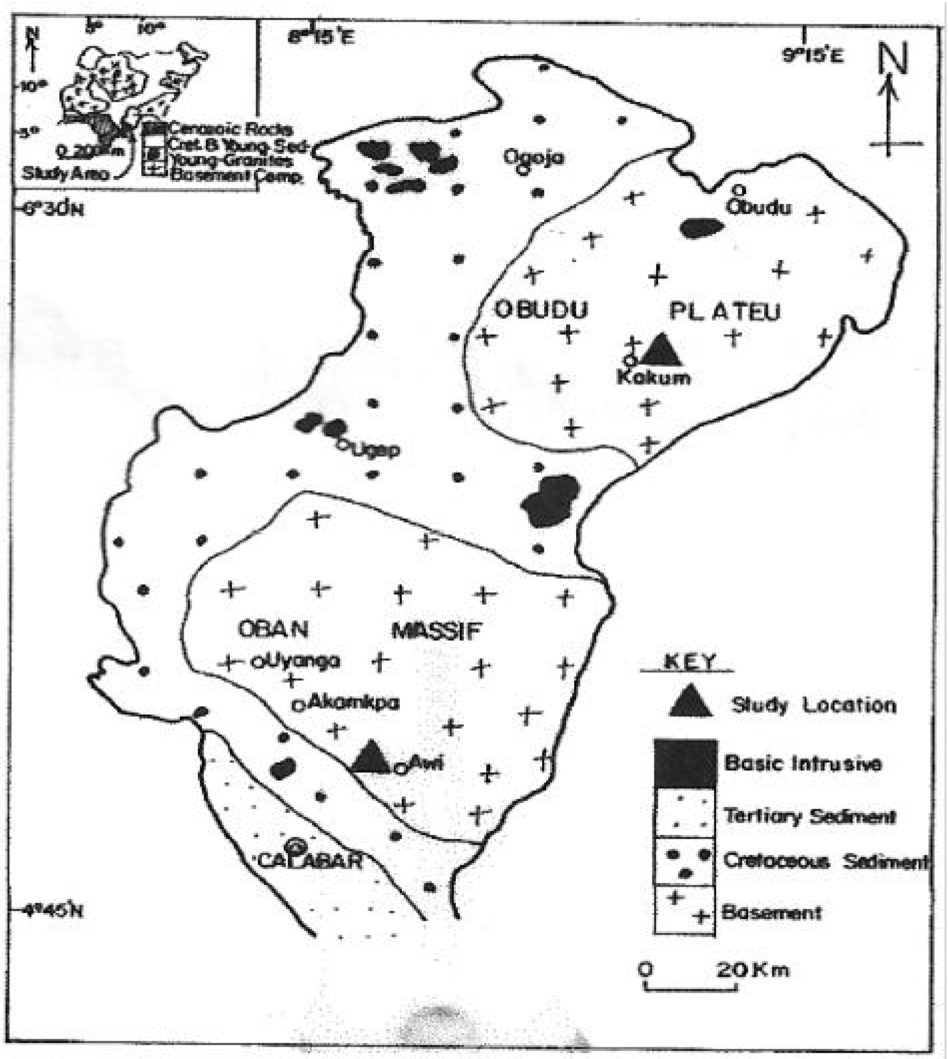

Fig. 1: Geologic map of study area (inset, sketch geologic map of Nigeria, after Ekwueme, 1995)

The area has elevation of about 1100m to 1576m. The rocks are predominantly migmatite - gneiss - schist complex and charnockite - enderbite - granite plutons while the subordinate rock units are amphibolites, quartzites, cataclastics, mylonites, gabbros, pegmatites, aplites and dolerites [19].

The Oban massif has a complex lithology and the differentiation of the rock types had remained difficult. The reason is that Oban Massif is located in the thick equatorial rain forest inhabited by wildlife. Additional reason is that the basement rocks in the area are generally intensely weathered and this makes it difficult to obtain fresh rock for geological studies. The oldest rock in the Oban Massif is the banded gneisses and dolorite is the youngest. Figure 1 shows the geologic map of the study area.

MATERIALS AND METHODS

Dc-resistivity survey using the square - array method was conducted in a manner similar to that of traditional collinear arrays. The location of measurement site was assigned to the center point of the square. The array can be expanded symmetrically about the center point, in increments of A (2)½ [20], where “A” is the square size, so that the sounding can be interpreted as a function of depth. Field arrangements are shown in figures 2a, 2b and 2c.

For each square, three measurements were made; two perpendicular measurements (alpha, α and beta β) and one diagonal measurement (gamma, γ). α and β measurements provide information on the directional variation of the subsurface apparent resistivity (ρ_a).

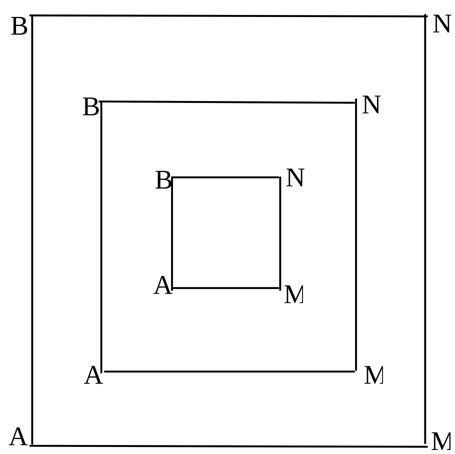

Fig. 2a: Field arrangement for depth sounding using square array

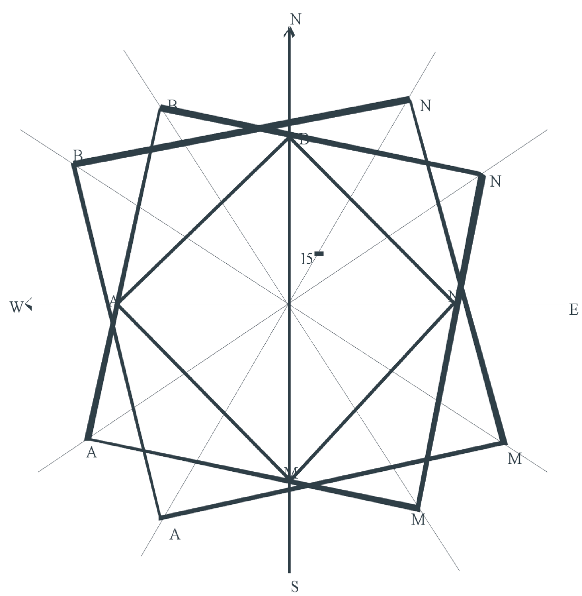

Fig. 2b: Field arrangement for azimuthal square array data collection, AB = Current Electrodes, MN = Potential Electrodes

The γ measurement serves as a check on the accuracy of α and β measurements. In an isotropic medium,

$$\rho_{a\alpha} = \rho_{a\beta}$$

Therefore, $\rho_{a\gamma} = 0$ (1)

and in a homogeneous anisotropic medium,

$$\rho_{a\gamma} = \rho_{a\beta} - \rho_{a\alpha} \qquad (2)$$

Where ρ_a= apparent resistivity, in ohm - meters.

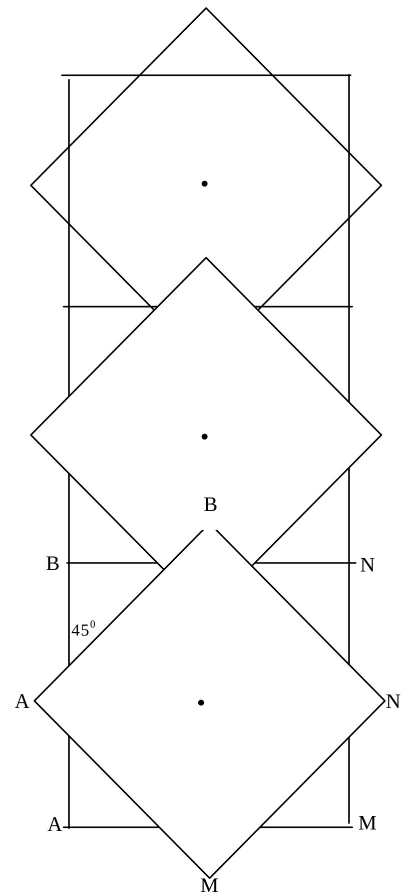

Fig. 2c: Field arrangement for crossed square - array dc resistivity profiling

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

$$r_a = \frac{K\Delta V}{I} \qquad (3)$$

Where

K = geometric factor, for a square of size equal to A

$$K = \frac{2rA}{2-(2)^{1/2}} \qquad (4)$$

Equation (4) is adopted after [20]. For this study, square sizes of 42.4m, 56.6m, 70.7m and 84.9m were used. Measurements were taken for $\rho_{a\alpha}$ and $\rho_{a\beta}$ for the initial position of the squares and similar measurement was taken when the square was rotated through an angle of 45°. These data constitute the crossed square array data and are those useful for the estimation of porosity. Figure 2b shows azimuthal square - array survey with each square rotated in 15° increments about the center, when the square is rotated through 45°, crossed square array data can be obtained for porosity estimation. Figure 2c shows a square-array profiling field arrangement.

In this case the square is moved along the profile and at each point rotated through 45° for crossed square array data. The analysis of data collected using the crossed squared array profiling method gives information about fracture zone location. The aim of conducting crossed square-array data collection was to locate the fracture point along the profile line. This was possible by plotting mean apparent resistivity against the center point of the square and also the secondary porosity in percent against the centre point of the square.

Data collected using square - array / crossed square array can be analyzed using a method described by [21]. Using the crossed-square array measurements, the secondary porosity can be estimated by modifying Taylor’s method developed for collinear arrays.

To calculate secondary porosity, it is first necessary to calculate the anisotropy “N” from the field data using [21], thus:

$$N = [(T + S)/(T - S)]^{1/2} \quad (5)$$

Where $T = A^{-2} + B^{-2} + C^{-2} + D^{-2}$ (6)

$$S = [(A^{-2} - B^{-2})^2 + (D^{-2} - C^{-2})^2]^{1/2} \quad (7)$$

Where

$$A = [(D_{a3} + 3D_{a1})/2 + (D_{a4} + D_{a2})/(2)^{1/2}][E]$$
$$B = [(D_{a1} + 3D_{a3})/2 + (D_{a2} + D_{a4})/(2)^{1/2}][E]$$
$$C = [(D_{a4} + 3D_{a2})/2 + (D_{a1} + D_{a3})/(2)^{1/2}][E]$$
$$D = [(D_{a2} + 3D_{a4})/2 + (D_{a3} + D_{a1})/(2)^{1/2}][E] \quad (8)$$

Where $E[2 + 2^{1/2}]$ (9)

D_{a1}, D_{a2}, D_{a3} and D_{a4} are constituent resistivity measurements from a crossed square array as shown in figure 2.

The secondary porosity, ì is then estimated using equations, 5, 6, 7, 8 and 9

$$\varnothing = \frac{3.41*10^4(N-1)(N^2-1)}{N^2 C(r_{max} - r_{min})} \quad (10)$$

Where, C is the specific conductance of groundwater in microsiemens per centimeter. ‘C’ ranges between 180μ s/cm to 220μ s/cm in the area. D_{max} and D_{max} are the maximum square - array apparent resistivity and minimum square - array apparent array resistivity respectively.

RESULTS AND DISCUSSION

Data collected at Awi, part of Oban Massif at five (5) sites with squares of size 42.4m, 56.6m and 70.7m and analyzed for fractured parameters show the range in secondary porosity of 0.0004 to 0.02 with coefficient of anisotropy ranging from between 1.03 to 1.40. Similarly, data collected at part of the Obudu Plateau and analyzed with squares of sizes 56.6m, 70.7m and 84.9m show range in secondary porosity of 0.009 to 0.005 with coefficient of anisotropy ranging from 1.03 to 1.20. Results obtained from the two geological setting discussed above have a good correlation. This means that there is no big difference between the fractured zones parameters obtained within Oban Massif and that obtained within the Obudu Plateau. The summary of the result is as shown in table 1. The results of crossed square- array dc-resistivity profiling conducted at Awi, Oban Massif are shown in figures 3a and 3b.

From the plot in fig. 3a and 3b, a decreased mean resistivity and an increased secondary porosity at a point are interpreted as fractures zones. Areas of decreased mean apparent resistivity are located between 60m and 100m and between 180m and 220m. Areas of decreased apparent resistivity and increased calculated secondary porosity are located at 60m and 180m. From the graphs above, the fracture zone is probably located at 60m and 180m. Data collected at Oban Massif were identified as OM while data collected at Obudu Plateau were identified as OP. The profile data are identified as OMP. From the results in table 1, the relatively high value of the fracture porosity at OM1, OM2, OMP and OP4 suggest that the rock mass in these locations are intensely fractured and more permeable. In contrast, the evaluated parameters at the remaining locations are indicative of rock mass being less intensely fractured and less permeable.

Table 1: Fractured parameter obtained from analyses of Azimuthal resistivity data from the study area

Site	A Spacing (m)	Coefficient of Anisotropy 8	Fracture porosity
OM1	42.4	1.20	0.003
OM2	66.6	1.40	0.02
OM3	56.6	1.03	0.001
OM4	70.7	1.11	0.008
OMP	40.0	1.17	0.003
OMP	40.0	1.28	0.01
OMP	40.0	1.04	0.0004
OMP	40.0	1.10	0.003
OMP	40.0	1.04	0.001
OMP	40.0	1.19	0.02
OP1	56.6	1.10	0.009
OP2	70.7	1.06	0.004
OP3	70.7	1.03	0.004
OP4	84.9	1.20	0.005

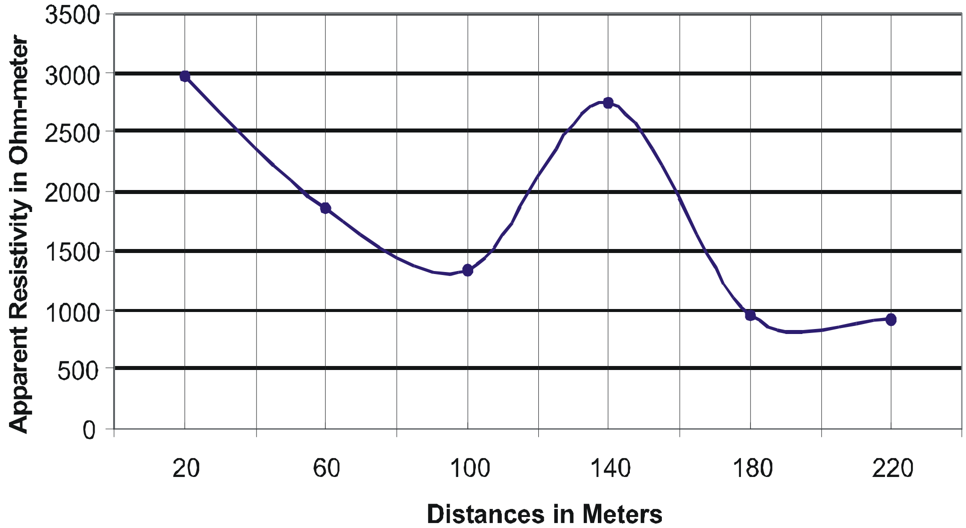

Fig. 3a: Apparent resistivity against distances at location OMP

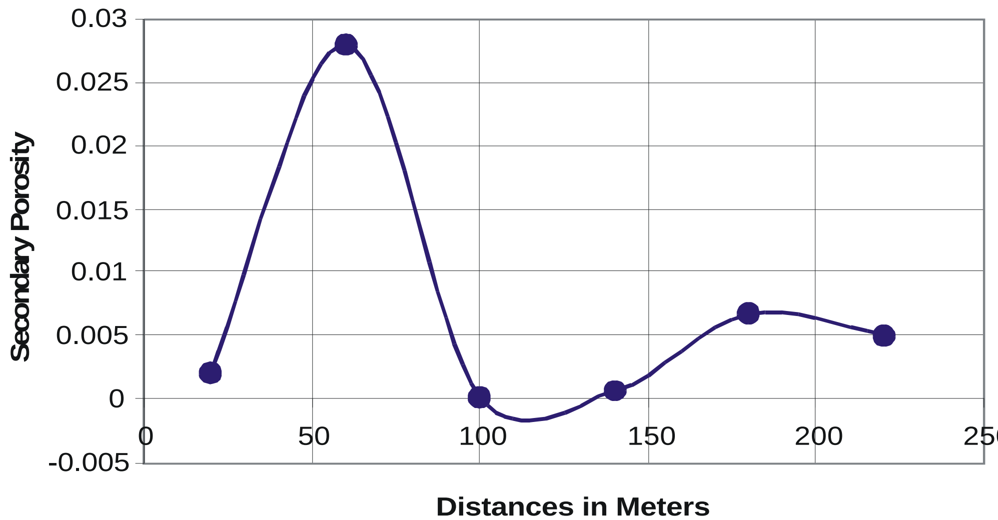

Fig. 3b: Secondary porosity against distances in meters

CONCLUSSION

Dc resistivity method was conducted at nine (9) sites within Oban Massif and Obudu Plateau using square array electrodes configuration. Analysis of data collected show the range of secondary porosity of between 0.003 to 0.02 at Oban Massif and 0.004 to 0.009 at Obudu Plateau. Crossed square array dc-resistivity profiling data analyses show that fracture zones are probably located underneath at 60m and 180m along the profile. This method and type of electrode configuration have been found to be very effective in secondary porosity estimation. However, due to non-uniqueness of geophysical methods a study using other methods of exploration is recommended.

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