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Orthogonal Azimuthal Cross-square Arrays Electrical Resistivity Technique's Kookiness on Detection for Angular Disposition of Electrical Anisotropy

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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Short Research Article

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ABSTRACT

The article gives an overview on the study that critically analysed the effect of azimuthal orientation of current electrodes on the detectability of angular disposition of vertical electrical anisotropy caused by geologic features. This is very useful in ascertaining the correct orientation of foliation plane for vertically fractured geologic system. Eight points were studied using a pair, named alpha and beta, of orthogonal azimuthal cross-square arrays by direct-current electrical soundings in order to isolate and establish the angular disposition of presumed hidden subsurface vertical fracture. The kookiness observed in the resultant field observations was in violation of the principle of reversibility of light raypath (Fermat's Principle), upon which the electrical resistivity principle is based. Thus ultimately, the work has reviewed the correlation between theory and field observations and predicted the cause of the kookiness. The angular kookiness (deviation) was linked to dipping of plane of foliation that is in practice assumed to be zero. Moreover, the study suggests that angle of rotation of array is suppose to be much smaller than the determined angle of dip for correct evaluation of dipping angle.

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1. INTRODUCTION

The cross-square array was used to study electrical anisotropy due to foliations in geologic materials. Anisotropy in conjunction with heterogeneity are deviations from isotropy and homogeneity of earth materials. In geophysical studies these features cause confusion during segregating the effect of one or the other. One advantage exploited is that homogeneity is scale dependent and thus its effect can easily be assumed. Moreover, reference can be made to a collected sample. Anisotropy for simple structured system can be identified, more easily for vertical foliation. This is the motive of this study. Azimuthal resistivity sounding (ARS) procedure was exploited in which cross-square array used was rotated about uniformly increased azimuths until a complete circle is covered and the step repeated with increased spacing of electrodes. The result of the analysis yielded angular dispositions of presumed foliation plane with increasing depth. The bane of the problem is that when a measurement with same procedure and same point is repeated but with perpendicular array, the result is expected to give direction of anisotropy of ninety degrees to the previous data set in agreement with theory, Fermat principle, but contrary angular dispositions were observed from two results at certain points. So the study attempted to provide explanation to the observed disagreements that despite their immense effect on electrical data were neglected by the geophysical community globally. The study discovered more plausible explanations to the causes of the deviations and highlights on the advantages of the approach.

2. AIM AND OBJECTIVES

The aim of the study is to review the result obtained from the analysis of data collected by the use of two orthogonally oriented azimuthal cross-square arrays to decipher the structural orientation of hidden geologic lineaments. Therefore the objectives are to evaluate the obliqueness/dipping variation of lineaments with increasing depth so as to generate understanding of the true dip of planes of foliations from the kookiness observed in the usage of the differently oriented arrays and thus to enhance better understanding and highlight advantages on usage of the two orientations instead of one. The analysis is expected to provide better understand of the origin of kookiness.

3. THEORY

According to Keller and Frischknecht [1] the potential at M due current source I located at distance r from M (Fig. 1) is given by

$$V_M = \frac{I\rho_m}{2\pi r\sqrt{1+\left(\lambda^2-1\right)\sin^2\phi\sin^2\alpha}} \qquad (1)$$

Where $\emptyset$ is the azimuth and α is the dip. From

Telford et al. [2].

Mean resistivity $$\rho_m = \sqrt{\rho_T\rho_L} \qquad (2)$$

Anisotropy $$\lambda = \sqrt{\frac{\rho_T}{\rho_L}} \qquad (3)$$

The ρ_L and ρ_T are respective longitudinal and transverse resistivities of the medium.

According to Lane et al. [3] and Telford et al. [2], the generalized expression for resistivity ρ of a region crossed over by current I that created a potential difference ΔV is given by

$$\rho = \frac{\Delta V}{I} K \qquad (4)$$

Where K is the geometrical vector. The value of K for cross-square array (Fig. 2) of side A (Lewis and Haeni [4]) is given by

$$K = \frac{2\pi A}{2-\sqrt{2}} \qquad (5)$$

The porosity **φ** according to Habberjam [5] is given by

$$\Phi = 3.41 \times 10^4 \frac{(\lambda-1)(\lambda^2-1)}{N^2C(\rho_{max}-\rho_{min})} \qquad (6)$$

Where ρ_{max} and ρ_{min} correspond to respective resistivity maximum and minimum obtained from the intercept about major and minor axes of resistivity ellipse. Note also ρ_max and ρ_min used in equation (6)

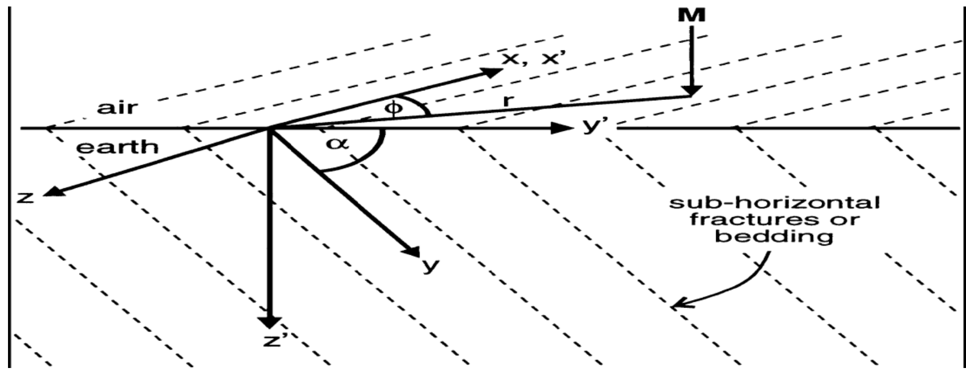

Fig. 1. Fractured system defining a generalised 2D resistivity

are synonymous to ρ_T and ρ_L in equations (2) and (3) respectively. Lane et al. [3], Habberjam [5] and Taylor [6] have given expository discussion on the utility of resistivity ellipses on identification of vertical plane of electrical anisotropy.

The simplification, and indeed the problem, on the application of the relation are in the synergy of choice of field dispositions of the electrodes. Anisotropy is displayed for vertical fractures. However, in the intermediate case of dipping anisotropy, the equipotential curves will still be ellipses but the elongation will be less, consequently, the anisotropy will not be fully characterized. The crux of the problem is how to evaluate the angle of dip from a deeply located dipping foliation plane?

4. METHODOLOGY AND DATA ANALYSIS

Here, the power of simplification by controlling the array position at the surface is exercised. The simplification is applied at the surface by taking measurements using a pair of current electrodes perpendicular and repeated with another pair parallel to surface manifested lineament. These values were determined by planting the pair of the current electrodes perpendicular (for alpha orientation) and parallel (for beta orientation) to the lineament according to equation (5) and the instrument gives the value of resistivity for each orientation in-turn according to equation (4). The values of resistivity obtained from such arrangements are respectively termed alpha and beta resistivities (Saleh and Likkason [7]). The data collected was plotted about polar axis and produced ellipses. The directions of minor axes of the ellipses were identified as foliation plane strike direction Saleh et al. [8]. Theoretically, minor axis of ellipse of anisotropy displayed by the two orientations will be 90º apart. Instead, anisotropy was observed to differ from this value at some instances. How does the deviation resulting from foliation plane be resolved in relation to assumption that the manifested lineament is surface displayed edge of a vertically oriented fracture? Looking at the resultant data (Table 1) obtained from the application of the two orientations of the array showed noncompliance with the theory at 7m, 20m, 28m and 50m depths. Where the square side length **A** is taken here is taken as the depth of investigation (Roy and Apparao [9]). The perceived cause of the deviation must be tilting/dipping of the plane of foliation. Thus the angle of dip of plane of foliation can be estimated from the angular difference indicated by difference in the direction of minor axes displayed by the two orientations of the azimuthal cross-square arrays.

4.1 Calculating Angle of DIP

To determine the angle of dip (α), take for example row 1 and row 2 in (Table 1).

Row 1: The angle Ø(^{o}) the minor axis makes with reference azimuth is 90^o and 0^o in the Alpha and Beta columns respectively (Figs. 3a and 3b). The difference between them is 90º in agreement with theory and field expected result. The data for this row correspond to a depth of investigation of 5.0m with polar plots shown in (Figs. 3a and 3b) for alpha and beta arrangements respectively.

Row 2: The angle Ø(^{o}) the minor axis makes with reference azimuth is 120º and 0º in the Alpha and Beta columns respectively. The difference between them is 120º, deviant from the theory and field expected result by 30º. This angle deviation from the expected result must have been contribution by dipping of the plane of foliation at the corresponding depth (7 m i.e. Row 2, column 2 in Table 1). Analysis of other rows follows the same pattern.

4.2 Discussion

The angular difference was 30º respectively. This was interpreted as being produced by dipping of fractures despite the incapacity to concretize on the direction as the perceived cause should only be due to tilting/bending of fracture, an occurrence that was uncontrollable. Therefore the dipping angle (α) for the plane of foliation was 30º at 7 m, 20 m, 28 m and 50 m respectively.

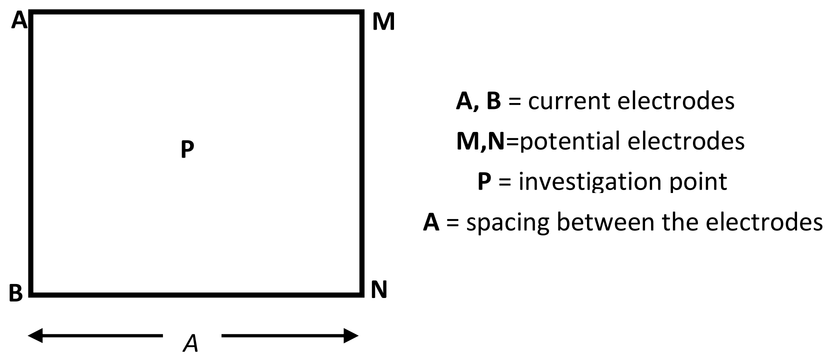

Fig. 2. Dispositions of electrodes about the vertices of a square

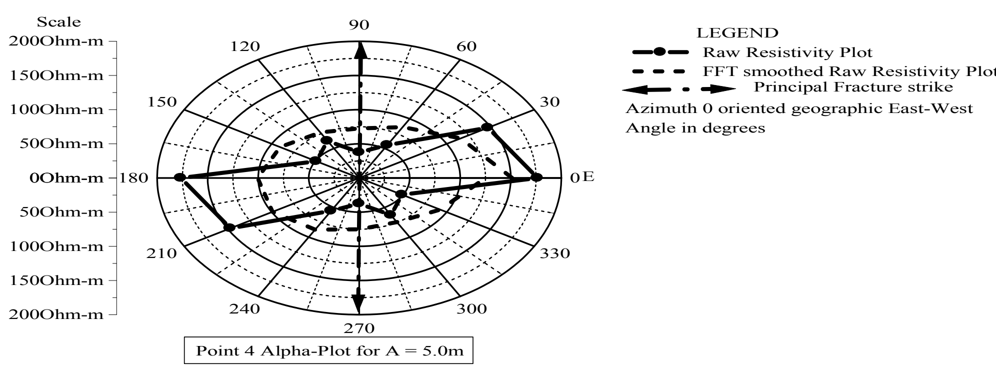

Fig. 3a. Point four alpha resistivity polar plot for 5.0 m depth

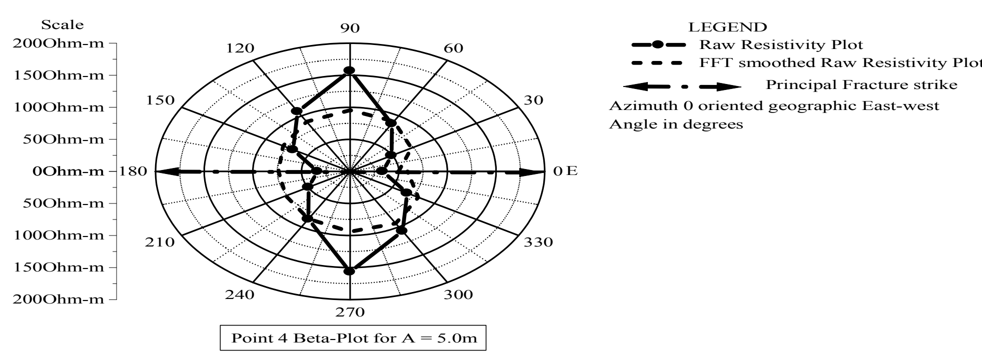

Fig. 3b. Point four alpha resistivity polar plot for 5.0 m depth

Table 1. Geoelectrical parameters for ARS fourth point

S/N	A(m)	Alpha orientation						Beta orientation					
		ρ_{max} (Ωm)	ρ_{min} (Ωm)	ρ_m (Ωm)	λ	Φ	Ø (°)	ρ_{max} (Ωm)	ρ_{min} (Ωm)	ρ_m (Ωm)	λ	Φ	Ø (°)
1	5	99.29	72.84	85.04	1.17	0.10	90	94.67	72.01	82.57	1.15	0.08	0
2	7	172.82	91.40	125.68	1.38	0.24	120	154.13	79.93	110.99	1.39	0.25	0
3	10	93.47	80.52	86.75	1.08	0.04	90	176.75	102.59	134.66	1.31	0.19	0
4	14	169.33	132.94	150.04	1.13	0.07	90	198.61	125.46	157.85	1.26	0.16	0
5	20	263.05	169.17	210.95	1.25	0.15	90	271.21	190.88	227.53	1.19	0.11	30
6	28	492.47	272.52	366.34	1.34	0.22	90	442.44	294.84	361.18	1.22	0.13	30
7	40	402.40	241.82	311.94	1.29	0.18	120	931.30	788.94	857.17	1.09	0.05	30
8	50	769.22	579.26	667.52	1.15	0.09	120	642.53	489.24	560.67	1.15	0.08	0
9	72	606.22	503.34	552.39	1.10	0.05	0,120	727.41	435.16	562.62	1.29	0.18	30
10	100	1784.27	1784.27	1784.27	1.00	0.00	xx	2240.46	2240.46	2240.46	1.00	0.00	xx

Inferred depth to bottom of the fracture = 80.74m; Fracture swath angle in degrees = 30; Oblique fracture angle in degrees = 0, Main Fracture angle in degrees = 120

As can be seen, this could be used to fully characterize the features as against the vertical foliation ($\alpha = 90^o$) assumed in the application of Equation 1 and (Fig. 1) in most anisotropy studies. Thus this approach could be used to follow flipping/swarthing of foliation plane at depths. Note the presence of two fractures at depth 72 m, as signified by two intersection foliations, one at 0º while the other at 120º, based on 90º dipping interpretation, that made this approach a little noncompliant.

5. CONCLUSION

The study showed that in studies for characterizing geological condition impregnated by fracture and if fracture study is an element, interpretation based on data obtained from two orthogonally oriented ARS array data suffices over one obtained from one array alone. The study has revealed the dipping angles (30º) of concealed plane of foliations. The importance of such inclusion becomes clear as fluid flow directions and response to vertical stress (principal stress) is greatly influenced by disposition of the plane of foliation.

It is recommended that a similar research be conducted but with smaller incremental Azimuthal angle, say five degrees, in order eliminate the effect of angle of rotation of array on calculated dipping angle as manifested in the present study. As is peculiar to all geophysical methods no amount of data is superfluous, complementary method (seismic) could be exploited as well.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Keller GV, Frischknecht FC. Electrical methods in geophysical prospecting, Pergamon Press, Oxford. 1970;517.
2. Telford WM, Geldart LP, Sheriff RE. Applied geophysics (10th ed.): New York, Cambridge University Press. 2009;755.
3. Lane GV, Haeni FP, Watson WM. Use of square-aaray direct-current resistivity method to detect fractures in crystalline bedrock in New Hampshire, Ground Water. 1995;33:476–485.
4. Lewis RA, Haeni FP. Use of square array direct-current resistivity methods to detect fractures in bedrock. An annonated bibliography, U. S. Geological Survey Circular. 1987;897:14.
5. Habberjam GM. Apparent resistivity, anisotropy and strike measurements, Geoph Prosp. 1975;23:211–247.
6. Taylor RW. The determination of joint orientation and porosity from Azimuthal resistivity measurements, U. S Environmental Protection Agency conference on surface and borehole geophysical methods in groundwater investigations. 1984;37–49.
7. Saleh M, Likkason OK. Geoelectric appraisal of lithostratigraphic patterns near North-East side of Downstream of the Tiga Dam, Kano State, NW Nigeria, Journal of Nigerian Institute of Physics, National Institute of Physics, Nigeria. 2011;56–61.
8. Saleh M, Likkason OK, Hassan M, Evaluation of fractured basement complex rock porosity by azimuthal cross-square vertical electrical soundings. Journal of Nigerian Association of Mathematical Physics. 2012;23(2):21-24.
9. Roy A, Apparao A. Depth of investigation in direct current methods, Geophysics. 1971;36:943–959.

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