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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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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 ninety degrees. Moreover, the study suggests that angle of rotation of array is suppose to be much smaller than the determine angle of dip for correct evaluationof dipping angle.

Keywords: Azimuthal, Kookiness, Orthogonal, Resistivity and Reversibility

1.0 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 setin 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.

2.0 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.

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3.0 Theory

According to [1] the potential at M due current source I located at distance r from M (Figure 1) is given by

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

Where ∅ is the azimuthand α is the dip angle. From [2]

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

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

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

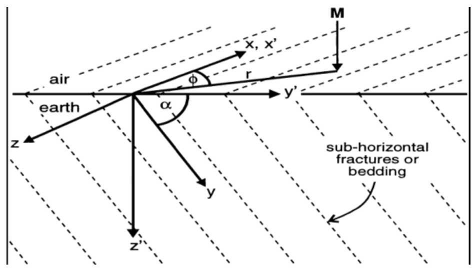

Figure 1:Fractured system defining a generalised 2D resistivity

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 equi-resistivity curves will still be ellipses but the elongation will be less, a deviation from Fermat's principle [3, 4], consequently, the anisotropy will not be fully characterized. The crust of the problem is how to evaluate the angle of dip from a deeply located dipping foliation plane?

Table 1: Geoelectrical Parameters of ARS Fourth Point

S.N	Depth (m)	Alpha					Beta				
		$\rho_{max}(\Omega m)$	$\rho_{min}(\Omega m)$	$\rho_m(\Omega m)$	λ	ϕ (°)	$\rho_{max}(\Omega m)$	$\rho_{min}(\Omega m)$	$\rho_m(\Omega m)$	λ	ϕ (°)
1	5	99.29	72.84	85.04	1.17	90	94.67	72.01	82.57	1.15	0
2	7	172.82	91.4	125.68	1.38	120	154.13	79.93	110.99	1.39	0
3	10	93.47	80.52	86.75	1.08	90	176.75	102.59	134.66	1.31	0
4	14	169.33	132.94	150.04	1.13	90	198.61	125.46	157.85	1.26	0
5	20	263.05	169.17	210.95	1.25	90	271.21	190.88	227.53	1.19	30
6	28	492.47	272.52	366.34	1.34	90	442.44	294.84	361.18	1.22	30
7	40	402.4	241.82	311.94	1.29	120	931.3	788.94	857.17	1.09	30
8	50	769.22	579.26	667.52	1.15	120	642.53	489.24	560.67	1.15	0
9	72	606.22	503.34	552.39	1.1	0,120	727.41	435.16	562.62	1.29	30
10	100	1784.27	1784.27	1784.27	1	xxx	2240.5	2240.46	2240.46	1	xxx
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 at depth of 72m											

4.0 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. The values of resistivity obtained from such arrangements are respectively termed alpha and beta resistivities [5]. 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, ϕ(°). The resistivity at edge of the minor axis which is represented as $\rho_T$under theory is symbolized asρ_{max} in Table 1, whereas ρ_L that corresponds to resistivity about the edge of major axis was represented byρ_{min} in order to give them practical connotation during their usage. See [6] for details on theprocedure.Theoretically, minor axis of ellipse of anisotropy displayed by the two orientations will be 90^0 apart. Instead, the angular dispositions of anisotropy were 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 50mdepths.

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. The difference between them is 90^o in agreement with theory and field expected result.
Row 2: The angle Ø(^{o}) the minor axis makes with reference azimuth is 120^o and 0^o in the Alpha and Beta columns respectively. The difference between them is 120^o, deviant from the theory and field expected result by 30^o. 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 Discussions

The angular differencewas 30^0 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 was30^0 at 7m, 20m, 28m and 50m respectively.
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 Figure 1 in most anisotropy studies.Thus this approach could be used to follow flipping/swathing of foliation plane at depths. Note thepresence of two fractures at depth 72m, as signified by two intersection foliations, one striking at 0^oazimuth while the other at 120^0, based on 90^0dipping interpretation. Presence of multiple fractures at a depth made this approach a little noncompliant.

5.0 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 (30^0) 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 to 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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