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ELECTRICAL ANISOTROPY OF CRYSTALLINE BASEMENT/SEDIMENT ROCK AROUND IFON, SOUTH-WESTERN NIGERIA: IMPLICATIONS IN GEOLOGIC MAPPING AND GROUNDWATER INVESTIGATION

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ABSTRACT

Nine radial vertical electrical soundings (RVES) were carried out around Ifon, South-western Nigeria, to determine the electrical anisotropy and map the trend of concealed structures. The results show that the concealed bedrock is anisotropic with the causative structural features comprising joints, foliations and faults. Dual structural trends observed at four of the RVES station were interpreted as intersection of structural elements at depth. The coefficient of anisotropy varies from 1.03 to 2.4 with a mean of 1.3. The bedrock resistivity shows an inverse relationship with the coefficient of anisotropy and localities with low bedrock resistivity may consequently indicate a fractured zone, which could favour groundwater storage. This is also true of sites with dual structural trends, where the interconnected structures aided groundwater movements.

Keywords: electrical anisotropy, RVES, mapping, groundwater investigation, Ifon, Nigeria.

INTRODUCTION

Anisotropy in prospecting has not been extensively used in geophysics despite the usefulness of electrical methods for detecting fluid - filled fractures (Mamah and Ekine, 1989). There has been comparatively little study of electrical conduction in fractures. Most of the reported work includes keys (1984) who studied resistively logs in fractured granite. In all cases of open and closed fractures there is marked reduction in resistivity logs in fractured granite.

Surface geological mapping and remote sensing methods including aerial photographs, side looking airborne radar (SLAR) and Landsat sensors are commonly employed in the identification of structural elements (Okurumeh and Olayinka, 1998). However, the usefulness of geological mapping is limited only to areas where the rocks outcrop.

In Southern Nigeria, remotely sensed data is of poor quality due to the masking effect of dense clouds, thick vegetation and short SLAR wavelength with limited look direction of SLAR (Gelnelt, 1978; Koopman's 1982; Ezenabor, 1985b). There is also the problem of accurate correlation of identified structural features on the basis of air photos and actual position on the ground due to the position fixing error (Ezenabor; 1985a).

Conversely, surface geophysical techniques can be invaluable in mapping the structural features of the concealed crystalline basement rocks (Olorunfemi and Opadokun, 1987) and in the detection of microfabrics resulting from basement tectonic in sedimentary terrain (Mamah and Ekine, 1989). Electrical anisotropy (or inhomogenity) of crystalline basement rocks is often attributed to structural elements like foliations, joints and fractures (Billings 1972; Malik, Bhattachyarya and Nag, 1973). It has been shown by (Odeyemi, Malomo and Okufarasin, 1985; Beeson and Jones, 1988; Okereke, Esu and Edet, 1993; Esu, 1993 and Edet *et al*., 1994) that the well yield in fractured rocks is directly related to the density, frequency, orientation and inter-connection of structural features at depth.

PHYSIOGRAPHY AND GEOLOGY

Ifon is situated between latitudes $6^0 45^1$N and $7^0 00^1$N and between Longitudes $5^0 30^1$E and $5^0 48^1$ (Figure-1). In the study area, there is generally a decrease in elevation from north to south reflecting the change from the basement to sedimentary terrain. The variation in lithology of the area has been characterized in parts by different physiographic features. The elevation in Ifon area is about 150m above the mean sea level, although in some places it may be as high as 250m.

The climate is tropical, typical of the sub-equatorial belt of the southwestern, Nigeria with mean annual temperature of 34^0C and mean annual rainfall of 1600-2000mm (Jones and Hockey, 1964). Ifon and its surrounding areas are underlain by Cretaceous and Tertiary rocks (Kogbe, 1970; Adegoke 1977 and Omatsola and Adegoke, 1982). Abeokuta Formation is the oldest unit here and it unconformably overlies the Precambrian basement rocks, just north of Ute. The Formation consists of conglomerates, sandstones, sands, siltstone, clays, shales, coal and thin limestone band. It is considered Neocomian to Palaeocene in age (Murat, 1972 and Adegoke, 1977).

METHOD OF INVESTIGATION

Radial Vertical Electrical Sounding (RVES) involves surface measurements of VES data along four different azimuths, namely 0^0, 45^0, 90^0 and 135^0. These correspond to an N-S, NE-SW, E-W and NW-SE geographical azimuths.

An ABEM Terrameter SAS 300B was used for resistance measurements and nine RVES stations were occupied (Figure-1). The SAS stands for signal averaging system - a method whereby consecutive readings are taken automatically and the results are averaged continuously

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thus increasing signal to noise ratio. The schlumberger configuration was employed, with a maximum current electrode spacing AB of 260m. The measurements were begun with 0^0 (i.e., N-S) azimuth while the successive azimuths were taken clockwise until the four directions have been so occupied. Apparent resistivity was plotted against half current electrode spacing for soundings at each station.

To determine the electrical anisotropy, the measured apparent resistivity (product of resistance and geometric factor) was plotted as a function of the rotation angles in polar co-ordinate for different values of AB/2. Since the emphasis in this RVES is on the degree of inhomogeneity and structural trends of concealed basement rocks, in relation to groundwater exploration, it was decided to restrict the polar diagrams mostly to large electrode spacing, these corresponding to the terminal branch of a VES curve.

INTERPRETATION AND DISCUSSIONS OF RESULTS

The deviation of a resistivity polar diagram from circularity to an elliptical shape defines an anisotropic medium, with the major axis of the ellipse corresponding to the strike direction of the structural features responsible for anisotropy (Keller and Frisechknecht, 1966). The coefficient of anisotropy for each RVES station occupied was obtained from apparent resistivity polar diagram using the ratio of the length of the major axis to that of the minor axis.

To determine the geoelectric parameters of the subsurface layers, a total of 36 sounding data were interpreted, these comprising four from each RVES station. Partial curve matching using two-layer master curves in conjunction with auxiliary diagrams were employed to obtain initial model parameters. These served as the basis for a computer assisted interpretation using Ghosh (1971) linear filters.

Typical sounding curves shown in Figures 2 to 4, represent localities with mean bedrock resistivity of <1000Ωm that could be classified as low while localities between 1000 to 3000Ωm are classified as intermediate and finally those greater than >3000Ω are classified as very high.

The geoelectric units are typical of those identified within the weathering profile developed upon crystalline basement rocks in low latitude environments. These are the topsoil, the regolith (an admixture of clay, sand clay, and clayey sand) and partially decomposed rock over the fresh bedrock. Table-1 gives a summary of the depth to the bedrock obtained from the sounding interpretation. The depth to bedrock in RVES stations 2, 5, 1, 6 and 3 is generally very shallow. However, for RVES stations 4, 9, 7 and 8 the reverse is the case. Stations 7, 8 and 9 with thickness of 66.35m, 72.4m and 44.45m respectively represent sedimentary terrain. This agrees with the geological map of Ifon area. The thinnest development of the weathering profile was encountered at station 2 where the mean is 2.725± 0.435m while the maximum was at station 8, with a mean of 72.4±9.689m. This suggests limited groundwater potential within stations 2, 5, 1, 6 and 3. Groundwater development within those stations should therefore be aimed at locating the fracture zones within the bedrock. The co-efficient of variation in the depth to bedrock obtained from the interpretation of the soundings taken at different azimuths is relatively low ranging from 6.92% to 31.14% with the exception of stations 4 and 6 having 56.21 and 43.85% respectively. This gives a rough idea of errors to be expected from sounding interpretation. The co-efficient of variations in the depth to bedrock agree with the results of the work of Okurumeh and Olayinka, (1998), around Okeho, Southwestern, Nigeria. Their results range from 6% to 19%. The slight difference in the result especially for stations 4 and 6 might be because while Okurumeh and Olayinka"s work was carried out entirely in the basement complex, the RVES in the present work was conducted in both basement and sedimentary terrain.

Table-1. Depth to bedrock (m) interpreted from the radii sounding at Ifon.

	Stn 1	Stn 2	Stn 3	Stn 4	Stn 5	Stn 6	Stn 7	Stn 8	Stn 9
0^0	10.8	3.3	12.6	46.3	13.5	12.6	60.0	85.0	37.0
45^0	10.3	2.8	9.5	38.2	6.7	17.2	70.0	73.9	42.5
90^0	12.1	2.5	17.4	9.5	13.0	4.8	49.8	61.7	42.4
135^0	10.9	2.3	9.6	22.7	8.9	12.2	85.6	69.9	55.59
Mean	11.025	2.725	12.28	29.125	10.525	11.7	66.35	72.4	44.45
Std dev	0.763	0.435	3.7	16.37	3.278	5.13	15.25	9.689	8.05
Var (%)	6.92	15.96	30.13	56.21	31.14	43.85	22.98	13.38	18.11

NB: STD Dev = Standard Deviation
Var. = Co-efficient of Variation

$$\% \text{ Variation} = \frac{\text{Std Dev} \times 100}{\text{mean}}$$

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The lowest bedrock resistivity was recorded at station 7, with a mean of 775±4443m (Table-2). On the other hand, the maximum was recorded at station 5, with a mean of 6863±1338Ωm. Values greater than 3000Ω-m as in RVES stations 4, 5, and 8, would suggest limited incidence of bedrock fractures the polar diagrams for all the stations are shown in Figure-5. The inferred structural trends and the co-efficient of anisotropy are presented in Table-3. They are classified into two; the first consists of N-S, NE-SW and NW-SE while the second comprises W-E direction. It may be noted that dual structural trends were recorded at stations 1, 3, 4, and 6 suggesting that the electrical anisotropy is in two dominant directions at these sites. This can be attributed to intersection of either joints or a joint and foliation.

Table-2. Bedrock resistivity (Ωm) interpreted from the radial sounding at Ifon.

		Stn 2	**Stn 3**	**Stn 4**	**Stn 5**	**Stn 6**	**Stn 7**	**Stn 8**	**Stn 9**
0^0	2011.2	1429.0	1716.6	2079.4	5674.8	2133.8	541.6	11234.3	2187.1
45^0	1722.8	1542.7	1854.7	8426.4	5873.7	3253.7	285.3	4960.4	1146.3
90^0	2093.7	1682.8	1480.1	3849.6	8505.6	2010.9	1722.7	3059.8	1695.0
135^0	1557.1	1173.7	1549.9	4055.6	7398.8	2704.9	550.3	2314.9	282.2
Mean	18846.2	1457.1	1650.3	4602.8	6863.2	2525.8	775.0	5292.4	1927.7
Std dev	249.85	215.54	168.55	2699.02	1338.62	571.75	643.66	4050.78	816.39
Var (%)	13.53	14.79	10.21	58.64	19.50	22.64	83.05	75.12	42.35

Table-3. The coefficient of anisotropy and inferred structural trend at Hon area.

Station	**A**	**Inferred structural trends**
1	1.25	NE-SW and N-S
2	1.26	W-E
3	1.13	N-S and W-e
4	2.40	W-E and NW-SE
5	1.30	W-E
6	1.25	NW-SE and NE-SW
7	1.21	N-S
8	1.11	N-S
9	1.03	NE-SW

The co-efficient of anisotropy for all the stations varies from 1.03 in VES 9 to 2.4 in VES 4 with a mean of 1.32. The values do not show any particular interrelation with the inferred structural trends. The abnormal co-efficient of anisotropy in VES 4 agrees with the abnormal shape of the polar diagram of station 4 and the classification of degree of homogeneity (Table-4), which shows that station 4 is very heterogeneous.

Table-4. The classification of degree of homogeneity.

Percentage deviation	**Co-efficient of anisotropy**	**Classification**
0-10	1.0-1.15	Very homogenous - A
11-15	1.16-1.25	Homogenous - B
16-40	1.26-1.35	Fairly homogenous - C
41-60	1.36-1.55	Heterogeneous - D
>60	>1.55	Very heterogeneous - E

There is no remarkable distinction between the co-efficient of anisotropy (1.3) obtained in this study which is essentially a combination of an igneous rock terrain and a sedimentary terrain with that reported in igneous terrain around Okeho (1.21) South-western Nigeria (Okurumeh and Olayinka, 1988). The depth to bedrock is not strongly dependent on the co-efficient of anisotropy. However, localities with low mean bedrock

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resistivity and a high co-efficient of anisotropy may indicate intense fracturing and such localities are potential sites for the drilling of water borehole. The inferred structural trends have been classified into two. The first group comprises N-S, NE-SW and NW-SE while the second consists of W-E. Linkages of structural trends could encourage the storage and movement of groundwater. However, this has to be confirmed by borehole drilling. The variation in the interpreted depth to bedrock and bedrock resistivities for the different azimuths at a given RVES stations are a reflection of the combined effect of computer model fitting error and deviations of the sounding from the reference structural trend, where the later is the strike direction of the major structure responsible for anisotropy.

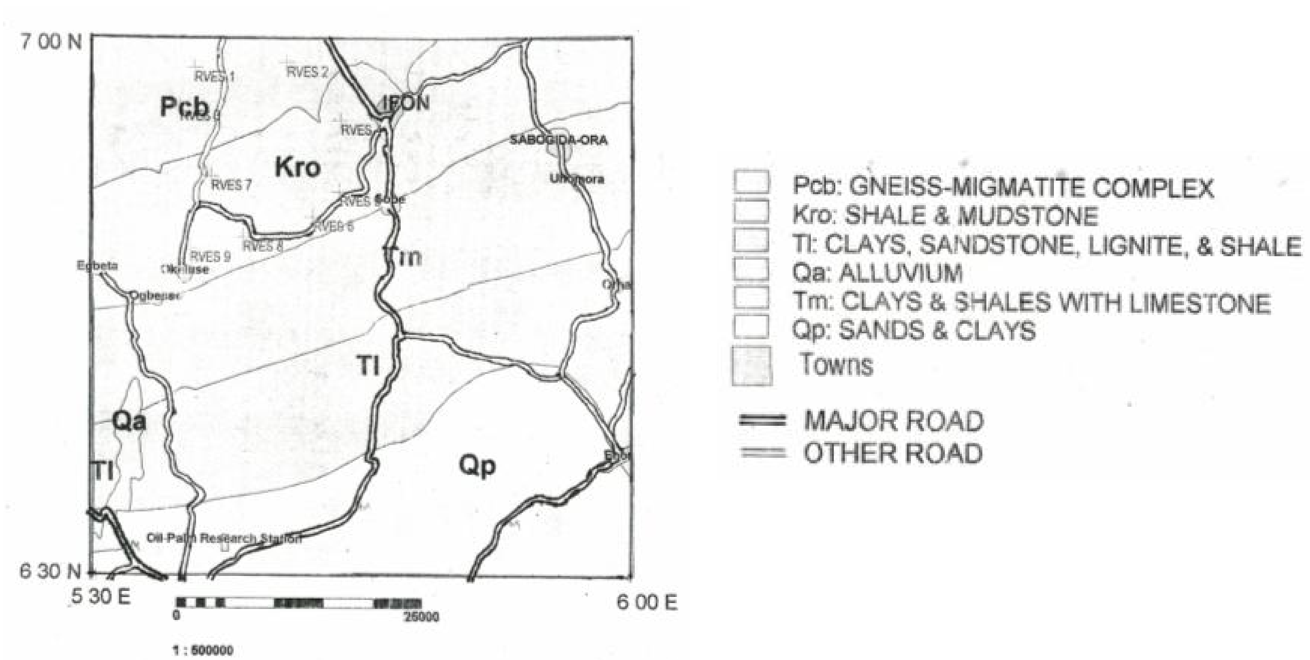

Figure-1. Geological map of Ifon area showing where RVES was conducted.

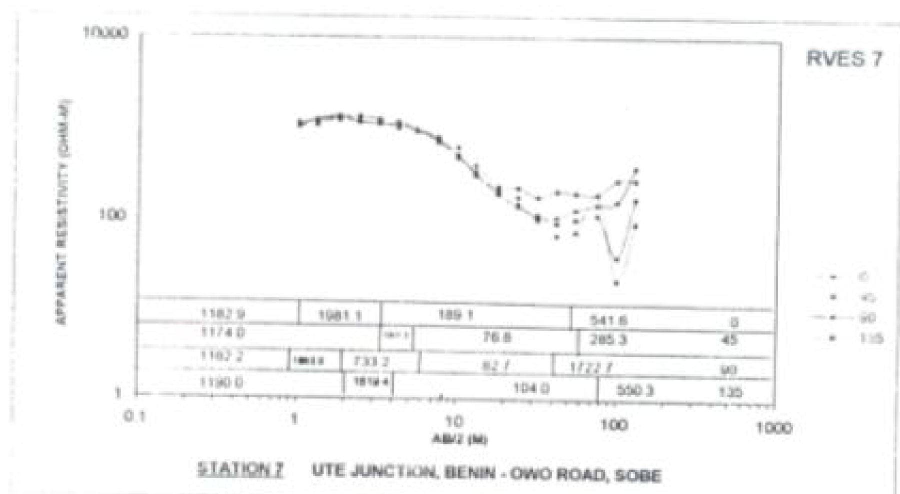

Fig. 2: Example of radial VES with relatively low bedrock resistivity.

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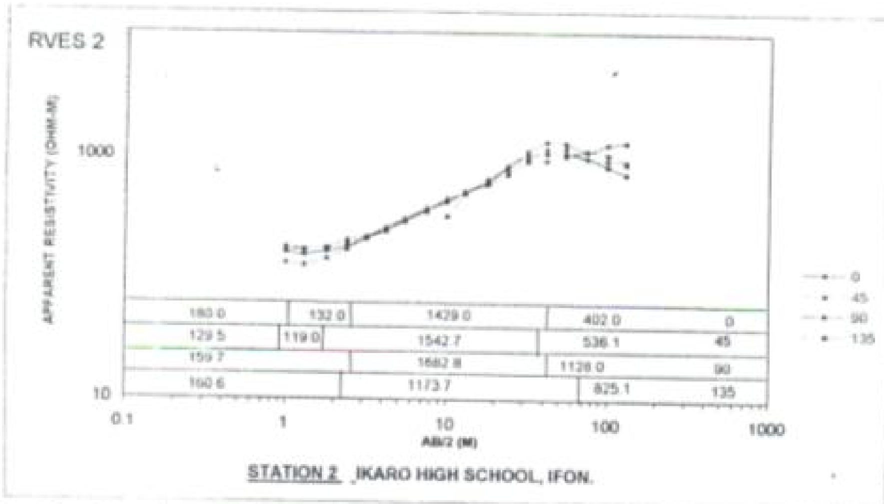

Fig. 3: Example of radial VES with relatively intermediate bedrock resistivity.

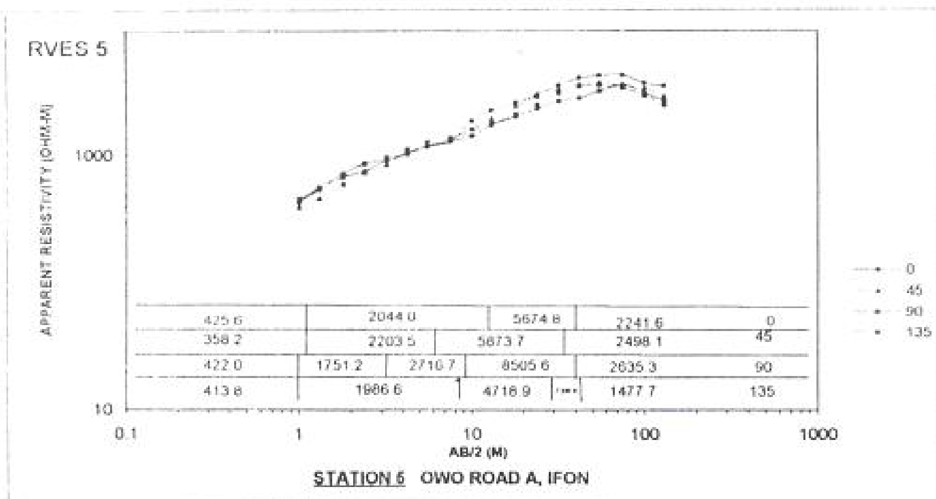

Fig. 4: Example of radial VES with an infinite bedrock resistivity.

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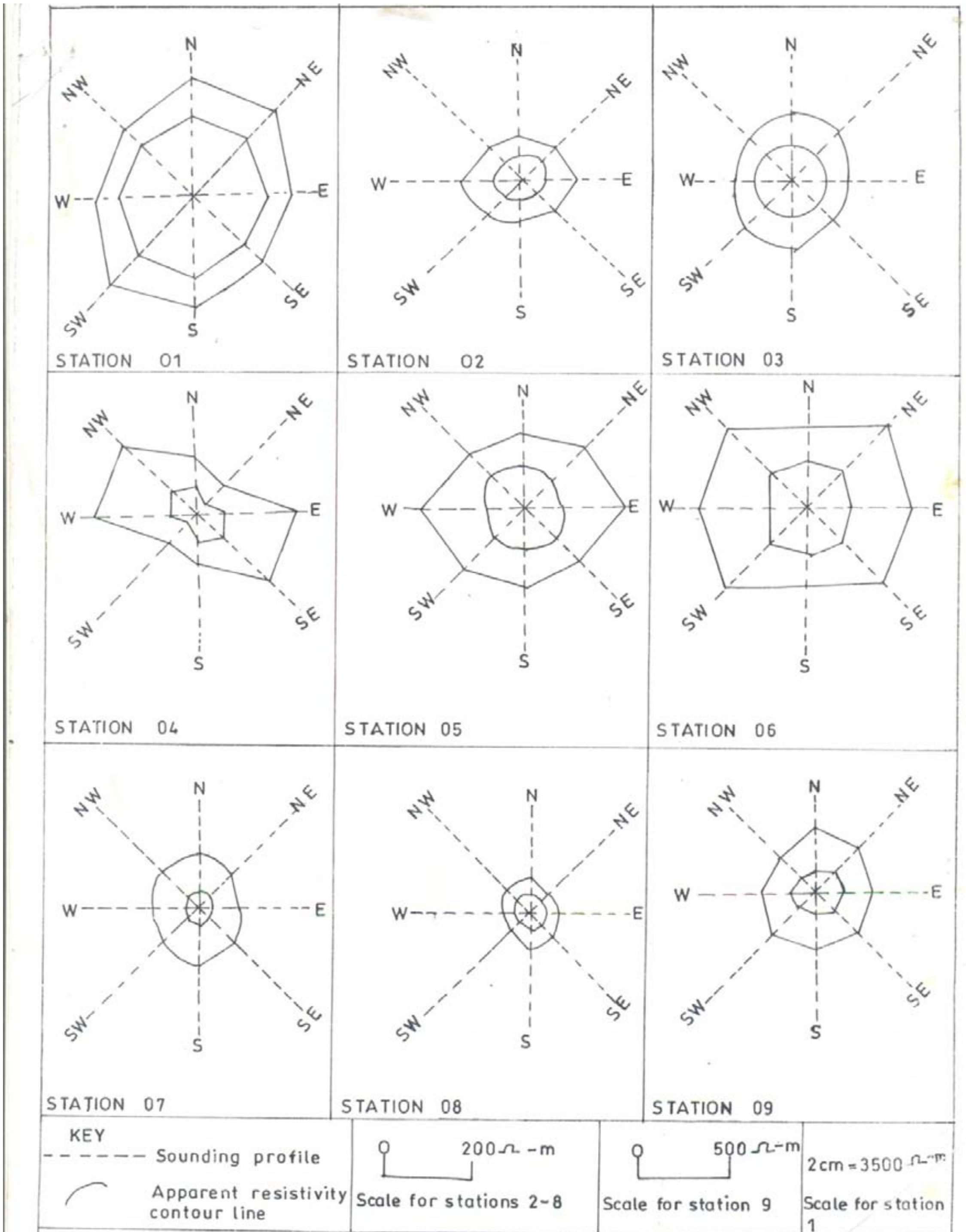

Fig. 5 Apparent resistivity polar diagrams for the respective radial VES stations.

CONCLUSIONS

The results have highlighted the importance of the use of RVES to detect electrical anisotropy and structural trends in the area. The major structural elements responsible for these structures include the joints, foliation and the fracture systems. The depth to the bedrock is not strongly dependent on the co-efficient of anisotropy. Localities with low mean bedrock resistivity and a high co-efficient of anisotropy may indicate intense fracturing and such localities are potential sites for the drilling of water-supply boreholes. The RVES interpretation reveals that the trends of rock fracturing were along N-S, NW-SE, NE-SW and occasionally W-E. The implication of this complex fracturing pattern is that the fractures will be interconnected and hence will form a good groundwater channel ways. It should be highlighted that any engineering structure that should be imposed on the area must have a firm and broad base foundation in order to avoid settlement problems due to the sub-surface fractures that abound in Ifon area.

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