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The effect of seasonal variation on the consistency of resistivity data.

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Abstract

It is a known fact that apparent resistivity values above the water level are affected by seasons **[5].** *It is therefore the aim of this paper is to confirm this effect in Rapele and to show that the lithology derived from the resistivity values for both wet and dry seasons are the same. Vertical electrical soundings (VES) using the Schlumberger array were conducted in the wet and dry seasons in one station and the linear filter method was used in the interpretation of the resistivity soundings. The results were accurate and they showed the same number of layers (same curve shape) and approximately the same layer thicknesses.*

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1.0 Introduction

Electrical prospecting method makes use of a variety of techniques, each based on some different electrical properties or characteristics of materials in the earth. The resistivity method is designed to yield information on bodies having anomalous electrical conductivity. It is mainly employed in geophysics to map bedrock, in ground water studies and to determine salinity. In most cases, near the surface electric conductivity is mainly controlled by porosity, water content and water quality.

For resistivity measurements, various electrode arrays can be utilized. However, if the earth is assumed to be horizontally stratified, isotropic and homogeneous media such that the change of resistivity is a function of depth, the Schlumberger array has been chosen for the purpose of this research. It has added advantage over other arrangements. The array is less sensitive to the influence of near surface lateral heterogeneities. Smoothing and interpretation techniques are much more developed for the Schlumberger array than other arrays.

The result of resistivity survey carried out was confirmed by well logs. Measurements were carried out both during the dry and wet seasons in one station.

2.0 Theory

The apparent resistivity of an inhomogeneous formation is given by [2] as:

$$\rho_a = 2\pi\left(\frac{1}{r_1}-\frac{1}{r_2}\right)^{-1}\left[1+\left(\lambda^2-1\right)sin^2\,\theta\; sin^2\,\alpha\right]^{1/2}\frac{\Delta V}{I} = K\,\frac{\Delta}{I} \qquad (2.1)$$

where k = geometric factor which depends on the array in use
α = *dip* of the anisotropy

$\theta =$ angle of strike
λ = coefficient of anisotropy = $(\rho_t / \rho_l)^{1/2}$
ρ_l = longitudinal resistivity parallel to abedding plane
ρ_t = transverse resistivity normal to the bedding plane
ΔV = potential difference and
r_1, r_2 = distances of surface electric potential from a point source of current, I.

The Schlumberger electrodes array was used for the purpose of this research. The geometric factor for the Schlumbeger array is given as:

$$K = \pi\left(\frac{a^2}{b} - \frac{b}{4}\right) \qquad (2.2)$$

where a = distance from the center of the array to the current electrode, b = distance between the potential electrodes. The technique of data interpretation used involves seeking a solution to the inverse problem namely the determination of the subsurface resistivity distribution from surface measurements. A very good solution to the inverse problem is the *kernel* function. It is used in interpreting apparent resistivity measurements in terms of lithological variation with depth. The function assumes the earth to be locally stratified, in homogenous and

isotropic layers and, unlike apparent resistivity function it is independent of electrode configuration. It cannot be measured in the field but has to be obtained from a transformation of measured apparent resistivities. The kernel function utilized in this work is derived after [1]. If the observed apparent resistivity is given by

$$\rho_a(r) = r^2 \int_0^\infty T(\lambda) J_1(\lambda r) dr \qquad (2.3)$$

Then the kernel function is given by [1] as:

$$T(\lambda) = \int_0^\infty \left(1/r\right) \rho_a(r) J_1(\lambda r)\ dr \qquad (2.4)$$

where J_1 is the first–order Bessel function of the first kind and $T(\lambda)$ is the transformed resistivity data. Dar–Zarrouk resistivity curve is independent of any underlying layers. The basic mathematics for graphical construction of Dar–Zarrouk curves are given by [6, 8]. The curves may be used to give true layer thickness h_j and resistivity ρ_j by the equation

$$h_j = \rho_j \left[\frac{L_{m\,j}}{\rho_{m\,j}} - \frac{L_{m\,j-1}}{\rho_{m\,j-2}}\right], \quad j = 1,2,3,\ldots\ldots,n \qquad (2.5)$$

$$\rho_j = \frac{L_{m\,j}\ \rho_{m\,j}}{L_{m\,j} / \rho_{m\,j}} - \frac{L_{m,j-1}\ \rho_{m,j-1}}{L_{m,j-1} / \rho_{m,j-1},} \qquad (2.6)$$

$$h_1 = L_{m1} \text{ and } \rho_1 = \rho_{m1} \qquad (2.7)$$

where $\rho_{mj} = (T_j / S_j)^{1/2}$, $L_{mj} = (T_j S_j)^{1/2}$, $T_j = \sum_{i=1}^{j} t_i$ and $S_j = \sum_{i=1}^{j} s_i \quad i = 1,2,3,\Lambda\ ,n.$, S = the total longitudinal conductance of a section of horizontal layers of thickness h_i and resistivity $[\rho_I]$. T = total transverse resistivity of the same layer above. The importance of Dar–Zarrouk function is that it is uniquely related to the apparent resistivity function.

3.0 Experimental work

Four electrode arrays are commonly used at the surface, one pair for introducing current into the earth, the other pair for measurement of the potential associated with the current.

The field procedure in the Schlumberger electrode array system is to expand the current electrodes successively while the potential electrodes remain fixed. This process yields a rapidly decreasing potential difference across the potential electrodes, which ultimately exceeds the measuring capabilities of the instrument. At this point a new value for potential electrode separation is selected typically 2 to 4 times larger than the preceding value and survey is continued. The distance between the potential electrodes must never exceed 2/5 of AB/2 where AB is the distance between current electrodes, the field measurements are usually conducted at AB/2 equals 1.0, 1.47, 2.15, 3.16, 4.64, 6.81, 10, 14.7, 21.5, 31.6, 46.4, 68.1, 100, 147 (i.e. six points per decade). The maximum separation depends on the geology of the area, the available space and the depth of interest. The instrument used was the Abem Terrameter SAS (signal average system) 300C with booster SAS 2000.

Four electrical resistivity soundings were conducted in one station in Rapele in December and January (for dry season), and September and October (for wet season), basically this is to determine the consistency of resistivity data with time. An array of 147m for the current electrodes used provided enough sub- surface information considering the depth of penetration in the Schlumberger array, which is 0.125AB [7].

4.0 Results and discussion

Low resistivity values indicate presence of water (or clay) in the formation. Resistivity depends on salinity of water, water saturation and occurrence of interaction among formations. The field curves obtained from these soundings were interpreted by applying the curve matching procedure and computer–based interpretation techniques [3].

The computer-assisted interpretation used for this project is based on the algorithm which employs digital linear filters, for the fast computation of the resistivity function for a given set of layers parameters [4] All data collected in the field were very consistent and of good quality. The geometric factor for Schlumberger array system was used in converting the digital data obtained from the field into apparent resistivity values.

These data with their corresponding electrode spacing data were plotted in a log- log graph, reduced and curve matched to obtain the trial earth models which were fed into a computer program written in accordance with the theory above to obtain the trial geoelectric sections after some iterative calculations.

The results showed that measured apparent resistivities defer for each VES (Tables 1 - 4), which confirmed the fact that apparent resistivities vary with the degree of wetness experienced during the wet and dry seasons. However, the field curves having the same shape, identified as QHK type curve (Figure 1) is an indication that they are all five layered geoelectric model (Tables 1 - 4). The same curve shape also indicated that the five layers have the same thichnesses as shown in Table 5 (though with a slight deviation of 3.5 – 11 percent, while the total depth penetrated deviated by only 8 percent).

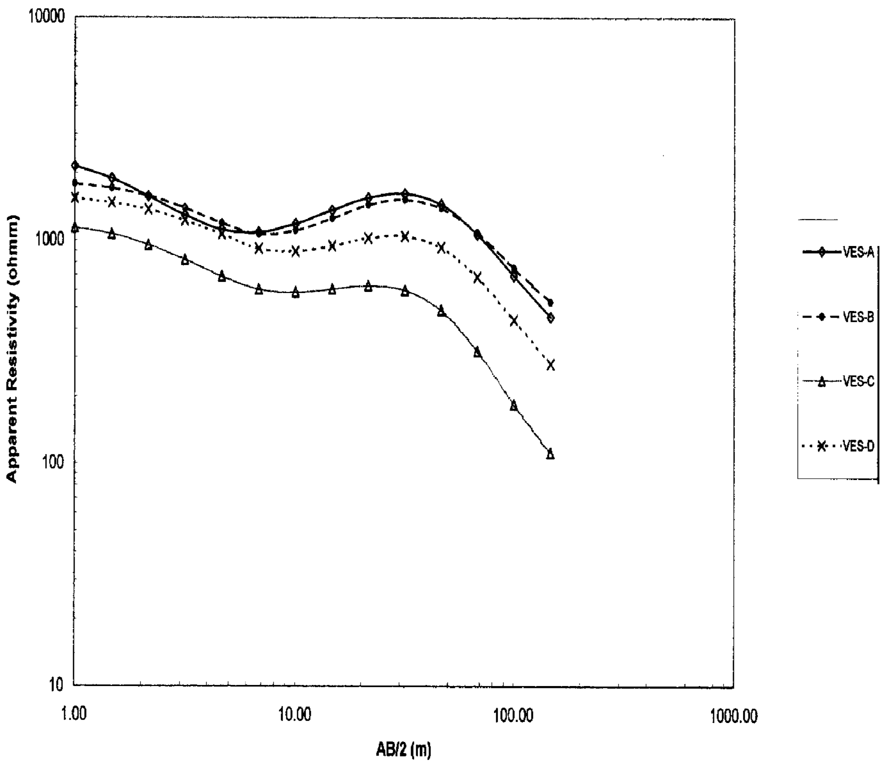

Figure 1: Resistivity curves for Schlumberger array, Rapele

Table 1: VES A, Rapele, December 1996

Model Interpretation

Layer	Resist.[Ω*m*]	Thickn. [*m*]	Depth [*m*]
1	2350.87	0.9	0.9
2	1007.30	1.5	2.4
3	900.00	4.4	6.8
4	2850.47	16.9	23.7
5	314.79	-	-

AB/2 [*m*]	Measured App.Res [Ω*m*]	Calculated App.Res [Ω*m*]	Dev.%
1.00	2.15k	2.15k	-0.0
1.47	1.99k	1.90k	-2.0
2.15	1.70k	1.58k	-3.2
3.16	1.36k	1.30k	-2.2
4.64	1.34k	1.12k	-7.7
6.81	1.06k	1.09k	1.3
10.00	1.19k	1.19k	-0.1
14.70	1.49k	1.37k	-3.7
21.50	1.73k	1.56k	-4.7
31.60	1.76k	1.63k	-3.4
46.40	1.53k	1.46k	-2.2
68.10	1.03k	1.07k	2.0
100.00	702.00	695.36	-.04
147.00	451.00	454.36	0.3

RMS = 3.12%

Table 2: VES B, Rapele, January 1997

Model Interpretation

Layer	Resist.[Ωm]	Thickn. [m]	Depth [m]
1	1850.75	0.9	0.9
2	1513.64	1.3	2.2
3	685.71	3.8	6.0
4	2475.09	18.8	24.8
5	408.98	-	-

AB/2 [m]	Measured App.Res [Ωm]	Calculated App.Res [Ωm]	Dev.%
1.00	1.78k	1.80k	-0.4
1.47	1.85k	1.72k	-3.1
2.15	1.77k	1.59k	-4.6
3.16	1.53k	1.40k	-3.8
4.64	1.18k	1.20k	0.6
6.81	957.00k	1.07k	4.9
10.00	1.06k	1.11k	2.2
14.70	1.28k	1.25k	-0.5
21.50	1.56k	1.45k	-3.2
31.60	1.69k	1.53k	-4.2
46.40	1.45k	1.40k	-1.7
68.10	1.06k	1.09k	1.1
100.00	756.60	755.60	-0.1
147.00	527.00	530.26	0.3

RMS = 2.76%

Table 3: VES C, Rapele, September 2003

Model Interpretation

Layer	Resist.[Ωm]	Thickn. [m]	Depth [m]
1	1200.00	0.9	0.9
2	800.00	1.4	2.3
3	435.00	3.5	5.8
4	787.50	22.0	27.8
5	85.06	-	-

AB/2 [m]	Measured App.Res [Ωm]	Calculated App.Res [Ωm]	Dev.%
1.00	1.14k	1.14k	-0.1
1.47	1.11k	1.07k	-1.7
2.15	1.06k	955.06	-4.5
3.16	874.86k	819.95	-2.8
4.64	676.38	692.42	1.0
6.81	576.24	605.35	2.1
10.00	602.59	588.34	-1.0
14.70	670.59	608.69	-4.2
21.50	700.79	629.42	-4.7
31.60	627.34	601.38	-1.8
46.40	455.50	489.34	3.1
68.10	281.50	320.39	5.6
100.00	184.11	184.10	-0.0
147.00	116.54	111.71	-8.1

RMS = 3.00%

Table 4: VES D, Rapele October r 2003

Model Interpretation

Layer	Resist.[Ωm]	Thickn. [m]	Depth [m]
1	1600.90	0.8	0.8
2	1309.09	1.6	2.4
3	614.93	4.0	6.4
4	1450.00	22.7	29.1
5	202.56	-	-

AB/2 [m]	Measured App.Res [Ωm]	Calculated App.Res [Ωm]	Dev.%
1.00	1.60k	1.55k	-0.6
1.47	1.57k	1.48k	-2.7
2.15	1.51k	1.38k	-3.9
3.16	1.31k	1.23k	-2.7
4.64	1.08k	1.07k	-0.4
6.81	914.00	924.14	0.5
10.00	857.00	896.35	1.9
14.70	971.00	949.06	-1.0
21.50	1.09k	1.03k	-2.5
31.60	1.20	1.05k	-5.8
46.40	993.00	935.24	-2.6
68.10	657.00	688.47	2.0
100.00	460.00	441.93	-1.7
147.00	273.00	279.86	1.1

RMS = 2.56%

Table 5: Interpreted results of VES taken in Dec.1996, Jan.1997, Sept.2003, and Oct.2003 in the same station in Rapele**.**

Layer	Thickness (*m*)				Mean thickness	Deviation of thickness expressed as % of mean thickness
	Dec., 1996	Jan., 1997	Sept., 2003	Oct., 2003		
1	0.9	0.9	0.9	0.8	0.875	3.5
2	1.5	1.3	1.4	1.6	1.45	6.5
3	4.4	3.8	3.5	4.0	3.925	7
4	16.9	18.8	22.0	22.7	20.10	11
Total Depth	23.7	24.8	27.8	29.1	26.35	8
Curve type	QHK	QHK	QHK	QHK	-	-

5.0 **Conclusion**

The research was carried out extensively in Rapele for the sole purpose of environmental study and the good quality of the results in terms of the close correlation among the VES obtained in led to a further study for the sake of this paper, low resistivity values were attributed to fresh water (or clay) and brackish water.

The general direction of ground water flow is coincident with topography and local ground water flow is radial and converges towards the Warri River.

The high correlation among the VES results obtained now confirms that VES interpreted geoelectric sections do not change with season and the authors advise that the usefulness of the electrical resistivity method for any purpose is not endangered by seasons provided the various precautions on the operation of the Terrameter taken. We hereby recommend that VES as a method can be applied in respective of seasons and results obtained during the dry season can be used as valid data in the wet season.

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The effect of seasonal variation on the consistency of resistivity data. *Otobo Egwebe and S. O. Ifedili. J. of NAMP*