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Non-uniqueness in the interpretation of resistivity sounding – II

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Abstract

Non-uniqueness in the interpretation of resistivity soundings is a known major problem in Vertical Electrical Soundings (VES) results because of the principle of equivalence and suppression. The aim of this paper is to demonstrate a solution to this problem in Ulogwe-Isumpe and Oriokan-Abavo both in Delta Sate of Nigeria. Five VES were conducted in Ulogwe-Isumpe and Oriokan-Abavo, boreholes were drilled one each in VES1 and VES 3 locations, for the purpose of correction of VES results by comparison between the obtained geoelectric sections from the VES curves interpretation and the borehole logs. And correlating the corrected geoelectric section with the sections of the other VES curves, the accepted geoelectric section (called the unique section) was generated for each VES curve. The accepted geoelectric sections for the other VES curves were confirmed by simple comparison of the sections with the logs of boreholes drilled at the location during the second phase of the field work. And the result showed a close correlation between the borehole logs and the accepted geoelectric sections.

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1.0 Introduction

It has been noted even from the early days of the application of VES method that there could be a considerably wide range of ambiguity of interpretation of VES field data. This means that strongly differing layer distribution in the subsurface may yield theoretical curves which, although they are not strictly equal, differ very slightly such that they would not be distinguished conclusively within the accuracy of the field measurement. In [1] this was pointed out to be due entirely to the relation between the resistivity transform and the parameters of the subsurface layer distribution. Thus, to select the model that best represents the true conditions of the subsurface, additional information is needed. This information may come in the form of borehole logs, geologic or topographic map, outcrops, springs electronic and any other geologic information.

However, the additional information which may come from borehole logs were only reported in [1] but how they are used in correcting non-uniqueness was not demonstrated. Therefore, in this paper we developed a scheme which requires only one borehole per study area drilled at a VES location for the purpose of confirming (or correcting) the geoelectric section obtained from the VES curve by comparison between the section and the borehole logs. This section (now called the unique geoelectric section for that VES) is used to obtain one geoelectric section for the other VES curves at location 50m apart by simple comparison with confirmed (or corrected) geoelectric section.

2.0 Theoretical analysis

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

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

where k = geometric factors which depends on the array in use

α = dip of the anisotropy

θ = angle of strike

λ = coefficient of anisotropy

ℓ_t = transverse resistivity normal to the bedding plane.

ℓ_l = longitudinal resistivity parallel 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 Schlumberger array is given as:

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

where a = distance from the centre 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, inhomogeneous and isotropic layer and, unlike apparent resistivity is given by

$$\ell_a(r) = r^2 \int_0^\infty T(\lambda) J_1(\lambda r)\, dr \tag{2.3}$$

Then, the kernel function is given by Ghosh (1971) as:

$$T(\lambda) = \int_0^\infty \left(\frac{1}{r}\right) \ell_a(r)\, J_1(\lambda r)\, dr \tag{2.4}$$

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 [3,4]. The curves may be used to give true layer thickness h_i and resistivity ℓ_i by the equation

$$h_j = \ell_j \left[\frac{L_{mj}}{\ell_{mj}} - \frac{L_{mj-1}}{\ell_{m,j-2}}\right], j = 1, 2, 3, \cdots n \tag{2.5}$$

$$\ell_j = \frac{L_{mj}\, \ell_{mj}}{L_{mj} / \ell_{mj}} - \frac{L_{m,j-1}\, \ell_{m,j-1}}{L_{m,j-1} / \ell_{m,j-1}} \tag{2.6}$$

$$h_1 = L_{m1} \text{ and } \ell_1 = \ell_{m1} \tag{2.7}$$

where $\ell_{mj} = \left(T_j / S_j\right)^{1/2}$, $L_{mj} = \left(T_j\, S_j\right)^{1/2}$,

$$T_j = \sum_{i=1}^{j} t_i \text{ and } S_j = \sum_{i=1}^{j} S_i, i = 1, 2, 3, \cdots n,$$

S = the total longitudinal conductance of a section of horizontal layers of thickness, h_i, and resistivity, ℓ_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.

Non-uniqueness comes as a result of either the phenomena of equivalence or suppression. The term equivalence is used in cases where the field curve or part of it expresses the H-type (bowl shape) such that $\ell_{i-1} > \ell_i < \ell_{i+1}$ or the k- type (bell shape) such that $\ell_{i-1} < \ell_i > \ell_{i+1}$. In the H-type cases, two resistivity curves stratifications can be equivalent, i.e. with undistinguishable apparent resistivity curves if they have the same values for the quotient t_i/ℓ_i. For the k-type cases, this situation arises for two stratifications which have the same values for the product $t_i \ell_i$.

The term suppression is used where the curve is ascending (A-type) where $\ell_{i-1} < \ell_i < \ell_{i+1}$ or descending (Q-type) where $\ell_{i-1} > \ell_i > \ell_{i+1}$. In both cases, the effect of the phenomenon is such that it may be impossible to detect at all the existence of the intermediate layer from the apparent resistivity curve. The equivalence rules have been formulated by [5].

3.0 Experimental work

The vertical electrical-resistivity sounding (VES) method involves injecting an artificially generated direct current or low frequency alternating current into the ground through two current electrodes as described by [6,7]. The resulting potential difference is measured by another pair of potential electrodes in the vicinity of the current flow. Although resistivity generally increases as porosity decreases, the electrical properties are controlled more by water quality than the resistivities of the rock matrix [8].

Vertical electrical resistivity soundings were conducted using the Schlumberger array and six points per decade. Five vertical electrical sounding stations were occupied using the ABEM SAS 300C Terrancter with Booster 2000 in Ulogwe-Isumpe (2 VES) and Oriokan-Abavo (3 VES) with an electrode separation of 1-681m. The resulting surrounding curves were interpreted by partial curve-matching [9] using two-layer model curves with the corresponding auxiliary curves and computer-iteration technique of [10].

4.0 Results and discussion

4.1 Ulogwe–Isumpe

The shapes of the VES curves represented by VES 1and 2 in Figure1 indicate apparent resistivity values of 100 Ohm-m and above meaning a sandy soil dominated area, with a mixture of clayey- sand layers shown by the middle bow section of the curves.

The geologic sections derived from the logs of borehole-1 drilled at VES1 location and the geoelectric section obtained from the interpretation of VES 1 are shown in Table 1. The geoelectric section in Table 2 obtained from the interpretation of VES2 (which include correlation of results with the geoelectric section of VES1 earlier corrected by the logs of borehole 1) corresponds to the logs of borehole 2 drilled later in the VES 2 location for the purpose of checking the uniqueness of the interpretation of VES 2 curve.

4.2 Oriokan –Abavo

The shapes of the VES curves represented by VES 3, 4 and 5 in Figure 1 like those of Ulogwe–Isumpe also indicate a sandy soil dominated subsurface with layers of clayey- sand within the sands.

Table 3 showed the geologic section derived from the logs of borehole 3 and the geologic section obtained from the interpretation of VES 3 after correction of VES interpretation by comparison with logs of boreholes 3. Tables 4 and 5 showed the geoelectric sections obtained from the interpretation of the curves of VES 4 and 5 and the geologic section derived from the logs of boreholes 4 and 5 drilled in VES 4 and 5 locations for the confirming the uniqueness of the interpretation of VES 4 and 5. Like the case of Ulogwe-Isumpe, the derived geoelectric sections of VES 4 and 5 correspond to the logs of boreholes 4 and 5.

However, the results from Ulogwe-Isumpe and Oriokan-Abavo have shown that with a good interpretation of VES curves coupled with correlation of derived geoelectric sections with the geoeletric section of a VES 50m away (whose section has been corrected by a borebole logs drilled at the VES location), one can obtain geoelectric section (called unique section) for the other VES in the area. Unique section here means the only section which satisfies the field curve and the logs of a borehole drilled at the VES location.

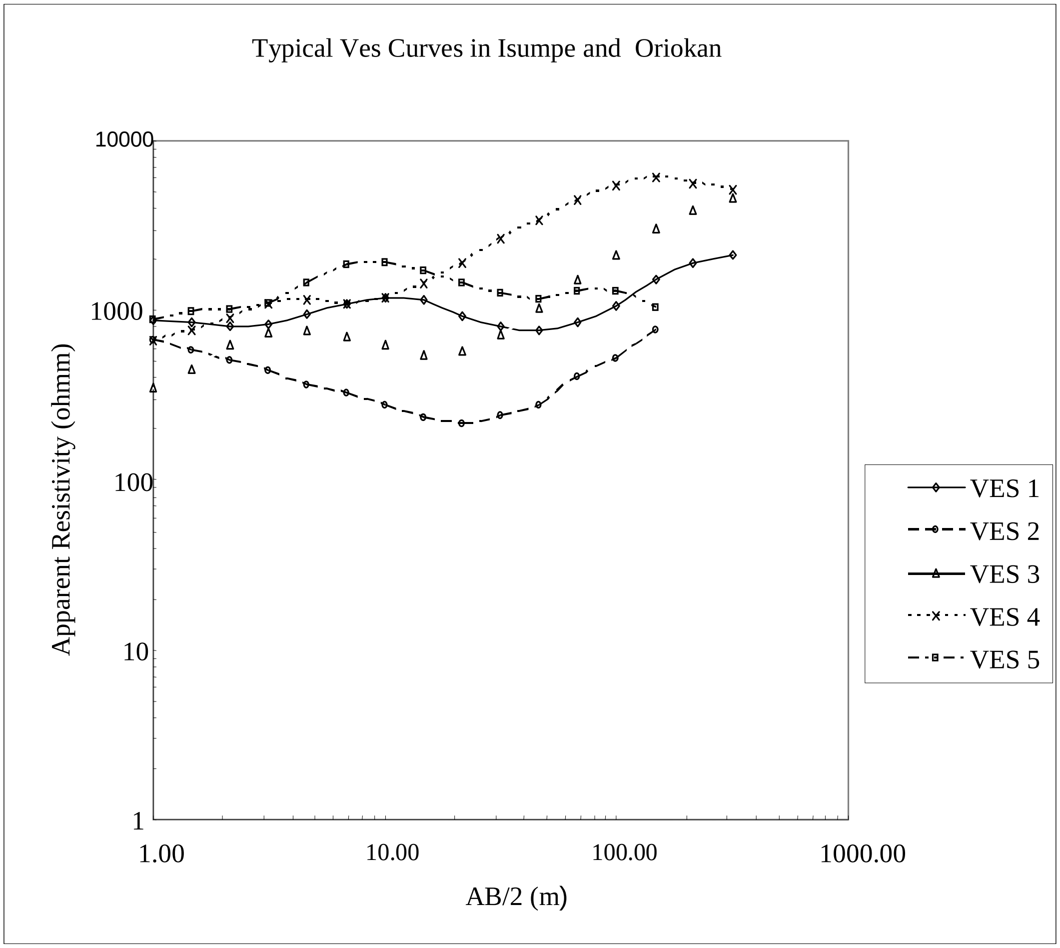

Figure 1: Computed VES curves for unique geoelectric sections in Ulogwe-Isumpe and Oriokan-Abavo.

Table 1: Geoelectric Section of VES 1 and the Geologic Section of borehole drilled at VES1 location in Ulogwe-Isumpe:

Layer	Geologic Section(Borehole logs)		Geoelectric Section(VES Curve)	
	Thickness (m)	Lithology	(Thickness (m)	Lithology
1	0.75	Sand	0.80	Sand
2	1.30	Clayey-Sand	1.20	Clayey Sand
3	3.70	Sand	3.68	Sand
4	51.00	Clayey-Sand	49.00	Clayey Sand
5	138.00	Sand	137.50	Sand
6	Substratum	Sand	Substratum	Sand

Table 2: Geoelectric Section of VES 2 and the Geologic of a borehole drilled at VES 2 location in Ulogwe-Isumpe

Layer	Geologic Section(Borehole logs)		Geoelectric Section(VES Curve)	
	Thickness (m)	Lithology	Thickness (m)	Lithology
1	1.00	Sand	0.90	Sand
2	5.70	Clayey-Sand	5.40	Clayey-Sand
3	25.00	Clayey-Sand	24.75	Clayey-Sand
4	Substratum	Sand	Substratum	Sand

Table 3: Geoelectric Section of VES 3 and the Geologic Section of borehole drilled at VES3 location in Oriokan-Abavo

Layer	Geologic Section(Borehole logs)		Geoelectric Section(VES Curve)	
	Thickness (m)	Lithology	Thickness (m)	Lithology
1	1.00	Clayey-Sand	0.85	Clayey-Sand
2	1.00	Sand	0.90	Sand
3	35.00	Clayey-Sand	36.00	Clayey-Sand
4	29.60	Sand	30.00	Sand
5	Substratum	Sand	Substratum	Sand

Table 4: Geoeletric Section of VES 4 and the Geologic Section of a borehole drilled at VES 4 location in Oriokan-Abavo

Layer	Geologic Section(Borehole logs)		Geoelectric Section(VES Curve)	
	Thickness (m)	Lithology	Thickness (m)	Lithology
1	0.85	Sand	0.95	Sand
2	1.90	Sand	1.80	Sand
3	8.00	Clayey-Sand	7.82	Clayey-Sand
4	11.50	Sand	11.00	Sand
5	115.00	Sand	114.00	Sand
6	Substratum	Sand	Substratum	Sand

Table 5: Geoeletric Section of VES 5 and the Geologic Section of a borehole drilled at VES 5 location in Oriokan-Abavo

Layer	Geologic Section(Borehole logs)		Geoelectric Section(VES Curve)	
	Thickness (m)	Lithology	Thickness (m)	Lithology
1	0.75	Clayey-Sand	0.70	Clayey-Sand
2	1.50	Sand	1.23	Sand
3	7.00	Sand	6.60	Sand
4	17.00	Clayey-Sand	16.32	Clayey-Sand
5	Substratum	Sand	Substratum	Sand

5.0 Conclusion

This work has shown that geophysicists can solve the non-uniqueness problem in the interpretation of resistivity sounding in an area by conducting 2 (two) or more VES at 50m apart with a borehole drilled at the location of one VES. This scheme has been applied to the interpretation of VES 2 (in Ulogwe-Isumpe) and VES 4 &5 (in Oriokan–Abavo), and the geoelectric sections obtained correspond to the logs of boreholes 2,4 &5 drilled in VES 2,4 &5 locations (see Tables 2,4 and 5).

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