THE EFFICIENCY OF RESISTIVITY METHOD IN DELINEATING LITHOLOGIC UNITS OF THE QUATERNARY DEPOSITS OF THE NIGER DELTA

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K. E. Aweto
Department of Geology, Delta State University, Nigeria
kizaweto@yahoo.com

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Abstract: The most widely used geophysical technique for groundwater prospecting is the Vertical electrical sounding. This method determines rock resistivity which is crucial for hydrogeological purposes because it allows differentiation between clayey materials and sandy aquifer. However, interpretation of sounding data has been subjected to ambiguities. In this study, Vertical electrical sounding data have been interpreted and used to delineate lithostratigraphic sequence of the Quaternary deposits of the Niger Delta. The delineated lithologies of geoelectric sequence were correlated with actual lithology based on driller's log obtained from boreholes drilled at the sounding locations. Efficiency of delineation using resistivity method varied between 63 – 90 %; the high positive correlation ($r^2 = 0.77$) between the delineated lithologies and actual lithologies shows that resistivity method can be efficiently used in delineating lithological sequence. The non-correlation between delineated and actual lithologies in few cases may be linked to equivalence.

Keywords: Resistivity, lithology, efficiency, delineation, log, correlation

Introduction

The basis of electrical resistivity method is to establish the subsurface resistivity structure from measurements made on the ground surface in which artificially generated direct currents are sent into the ground and the resultant potential differences are measured at the surface by the means of two metal probes (potential electrodes). It is possible to understand the nature of the subsurface layers from measurements of these potential. Generally the electrical attributes of the subsurface materials are useful in predicting zones that can serve as suitable aquifers. In time past, the drilling of boreholes was done blindly without prior investigation, and this often resulted in failed boreholes and non-production. However, in recent times, emphasizes is towards a scientific and technologically driven method aimed at delineating areas with enhanced potential for consequent exploitation (Olatunji *et al.*, 2007).

The electrical sounding method is useful for the deduction of the number and thickness of geoelectric layers, estimation of depth to bedrock depth to water table as well as aquifer thickness as well as other phenomenon (Telford *et al.*, 1990; Kearey and Brooks, 1996; Arshad *et al*., 2007; Yilmaz and Marschalko, 2011; Metwaly *et al*., 2012; Meshram and Khade, 2015). The determination of lithologic layers from geoelectric data is not direct in electrical prospecting. Generally, the resistivity of a soil or rock is regulated mainly by the conditions in the pore space. Hence, there are broad ranges of resistivity for any specific lithology or rock type and as a result resistivity values may not be exactly interpreted in terms of lithology. But however, zones of characteristic resistivity can be linked with specific lithology.

Electrical resistivity analysis is not exclusive because there are ambiguities associated with sounding curve interpretation. Due to differential in resistivity and absence of good resistivity contrast, the resolution of vertical electrical sounding has been less exact and thus the parameters interpreted could be ambiguous. According to Ernston and Kirsch (2006), modeling and interpretation of sounding curves is inextricably associated with the principle of equivalence. Equivalence in sounding data is basically analogous with many physically equivalent models that may differ considerably. More than one model may give an acceptable fit to the data (principle of equivalence). It is also possible that some layers that are thin or have a small contrast in resistivity will not be resolved (principle of suppression). For valid interpretation of sounding data it is imperative to take other data source such as geologic and hydrogeologic information into consideration (Oyinloye and Ademilua, 2006; Kumar *et al*., 2007; Yilmaz and Marschalko, 2011). Kumar *et al*. (2007) used a procedure combining sounding data and geostatistical approach based on the variographic analysis of thickness of the layers determined from borehole logs. This present study is directed at assessing the efficiency of resistivity method in delineating lithology by correlating geoelectric section of resistivity data with driller's lithologic log.

Materials and Method

Location and geology

The study area includes: Eku, Otor – Jeremi, Benisede, Ibusa, Oleh, Olomoro, Uzere, Orerokpe and Ekakpamre. They are located within longitudes 5° 35' E and 5° 58' E and latitudes 5° 20' N and 5° 55'N. The areas fall within the Tertiary Niger Delta which is a miogeoclinal accumulations formed at the edge of the rifting Atlantic Ocean. Three major lithostratigraphic successions underlie the Niger Delta (Reyment, 1965; Short and Stauble, 1967; Murat, 1970; Ejedawe *et al*., 1984; Kogbe, 1989; Reijers *et al*., 1997; Reijers, 2011) and they include the marine shales (Akata Formation), paralicfacies of shale and sand (Agbada Formation) and continental sands (Benin Formation). These are overlain by the Quaternary deposits comprising of rapidly alternating sequences of sand, silt and clay with the clays becoming more predominant towards the coastal parts of Nigeria (Etu-Efeotor and Akpokodje, 1990).

Methodology

In this study, the electrical resistivity sounding technique involving Schlumberger configuration was employed considering its cost effectiveness, high depth probing capabilities and sensitivity to subsurface in homogeneities (Ako, 1996; Sharma, 1997; Soupioset *al*., 2007; Kumar *et al*., 2007). The data were acquired at twenty (20) locations where boreholes were drilled for groundwater supplies using ABEM SAS 1000 Terrameter. The current electrode spacing was varied between 1.0 and 150 meters. The resulting sounding curves were interpreted by partial curve matching and computer iteration (Koefoed, 1979; Orellana and Mooney, 1996; Vander Velpen, 1988).

Geoelectric layers were delineated on the basis of existing electrical resistivity contrast between subsurface lithological sequences (Dodds and lvic, 1998). The delineated geoelectric layers were compared with lithologic units of driller's log to observe any correlation or agreement. A score of zero indicated non-agreement; a score of 1 was allocated to cases of partial correlation while a score of 2 was allocated to cases of complete agreement. Equation 1 was used in assessing the efficiency i.e. percentage agreement between delineated lithologies and actual lithologies.

$PA = \frac{\Sigma DS}{\Sigma MDS} \times 100\%$………… (1) (Oyinloye and Ademilua, 2006)

Where PA is percentage agreement, DS is delineation score and MDS is maximum delineation score.

Results and Discussion

Typical modeled resistivity curves and geoelectric parameters are presented in Fig. 1; the geoelectric section of these parameters were correlated with lithology logs as shows in Figs. 2 – 7. The assessment of efficiency of resistivity in delineating lithologies is shown in Table 1. The results showed that the efficiency of resistivity method in varied between 63 - 90%.

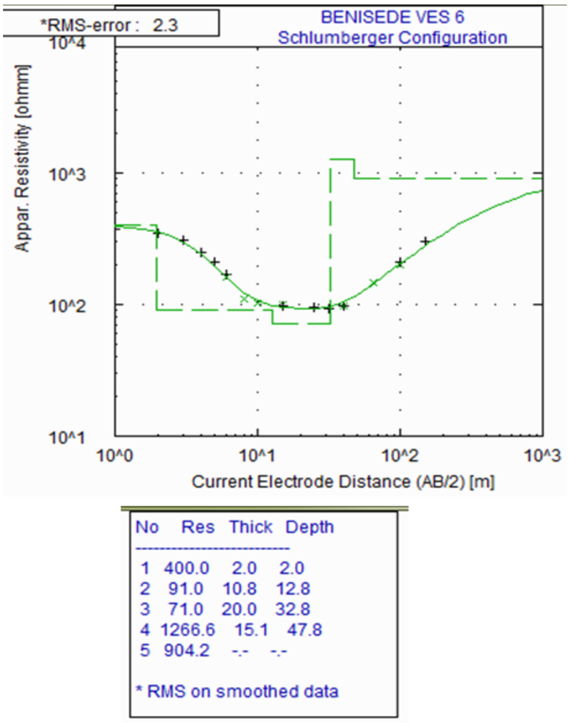

Fig. 1: Typical modeled resistivity sounding curves from location 6

Table 1: Assessment of efficiency of resistivity method in delineating lithology

VES	Delineated lithology	Actual lithology	D	PD	ND	DS	MDS	Efficiency (%)
1	Sandy clay	Laterite			√	0	2	
	Clay	Clay	√			2	2	
	Sand	Sand	√			2	2	
	Total					4	6	67%
2	Sandy clay	Sandy clay	√			2	2	
	Clayey sand	Clay		√		1	2	
	Sand	Sand	√			2	2	
	Total					5	6	83%
3	Sandy clay	Clayey sand		√		1	2	
	Fine sand	Fine sand	√			2	2	
	Coarse sand	Coarse sand	√			2	2	
	Total					5	6	83%
4	Sand	Sand	√			2	2	
	Clay	Fine sand			√	0	2	
	Medium sand	Medium sand	√			2	2	
	Coarse sand	Coarse sand				2	2	
	Total					6	8	75%
5	Sand	Sandy clay			√	0	2	
	Sandy clay	Sandy clay	√			2	2	
	Fine sand	Fine sand	√			2	2	
	Clayey sand	Clayey sand	√			2	2	
	Coarse sand	Coarse Sand	√			2	2	
	Total					8	10	80%
6	Sand	Sand	√			2	2	
	Clay	Sandy clay		√		1	2	
	Clay	Clay	√			2	2	
	Coarse sand	Coarse sand	√			2	2	
	Medium sand	Medium sand	√			2	2	
	Total					9	10	90%
7	Clay	Sand			√	0	2	
	Laterite	Laterite	√			2	2	
	Sand	Sand	√			2	2	
	Clay	Sandy clay		√		1	2	
	Sand	Sand	√			2	2	
	Total					7	10	70%

8	Clayey sand	Clay		√		1	2	
	Sandy clay	Sandy clay	√			2	2	
	Clay	Laterite			√	0	2	
	Coarse sand	Coarse sand	√			2	2	
	Coarse sand	Coarse sand	√			2	2	
	Total					7	10	70%
9	Laterite	Laterite	√			2	2	
	Sandy clay	Clay		√		1	2	
	Clay	Clayey sand		√		1	2	
	Sand	Sand	√			2	2	
	Clay	Sand			√	0	2	
	Sand	Sand	√			2	2	
	Total					8	12	67%
10	Clay	Clay	√			2	2	
	Clay	Clayey sand		√		2	1	
	Sand	Sand	√			2	2	
	Sand	Sand	√			2	2	
	Total					8	7	88%
11	Sand	Sand	√			2	2	
	Clayey sand	Clay		√		1	2	
	Sand	Sand	√			2	2	
	Total					5	6	83%
12	Sand	Sand	√			2	2	
	Laterite	Clay			√	0	2	
	Sand	Sand	√			2	2	
	Total					4	6	67%
13	Clayey sand	Sand		√		1	2	
	Clay	Clay	√			2	2	
	Fine sand	Fine sand	√			2	2	
	Medium sand	Medium sand	√			2	2	
	Total					7	8	88%
14	Clay	Sandy clay		√		1	2	
	Clay	Clay	√			2	2	
	Clayey sand	Fine sand		√		1	2	
	Coarse sand	Coarse sand	√			2	2	
	Total					6	8	75%
15	Clayey sand	Clay		√		1	2	
	Coarse sand	Fine sand		√		1	2	
	Coarse sand	Coarse sand	√			2	2	
	Total					4	6	67%
16	Sand	Sand	√			2	2	
	Clayey sand	Laterite			√	0	2	
	Sand	Sand	√			2	2	
	Sand	Sand	√			2	2	
	Total					6	8	75%
17	Sand	Sand	√			2	2	
	Clay	Laterite			√	0	2	
	Coarse sand	Medium sand		√		1	2	
	Coarse sand	Coarse sand	√			2	2	
	Total					5	8	63%
18	Clayey sand	Sand		√		1	2	
	Medium sand	Medium sand	√			2	2	
	Coarse sand	Coarse sand	√			2	2	
	Coarse sand	Coarse sand	√			2	2	
	Total					7	8	88%
19	Sand	Sand	√			2	2	
	Coarse sand	Clay			√	0	2	
	Fine sand	Fine sand	√			2	2	
	Coarse sand	Coarse sand	√			2	2	
	Total					6	8	75%
20	Sand	Sand	√			2	2	
	Clay	Fine sand			√	0	2	
	Coarse sand	Coarse sand	√			2	2	
	Total					4	6	67%

D = Delineated, PD = Partially delineated, ND = Not delineated, DS = Delineation score and MDS = Maximum delineation score

From the assessment of the efficiency of resistivity method in delineation of lithology at Eku (location 1 & 2), the result shows percentage agreement of 67 and 83% between delineated and actual lithology at these location respectively. At Otor – Jeremi (Figs. 2 & 3), it shows agreement levels of 83 and 75% between delineated lithology and actual lithology at locations 2 and 3, respectively. Around location 3, the first layer was partially delineated as sandy clay instead of clay while at location 4, the second layer was not delineated correctly (clay was delineated while it was actually sand). A correlation of lithological evaluation from resistivity sounding data and lithological logs at location 5 and 6 (Benisede) shows a percentage agreement or efficiency of 80 and 90 % respectively between delineated lithologies and actual lithologies (Fig. 4). At location 3, the first layer was delineated as sand instead of sandy clay while the underlying four layers were correctly delineated; at location 4, the first, third, fourth and fifth layers were correctly delineated while the second layer was partially delineated.

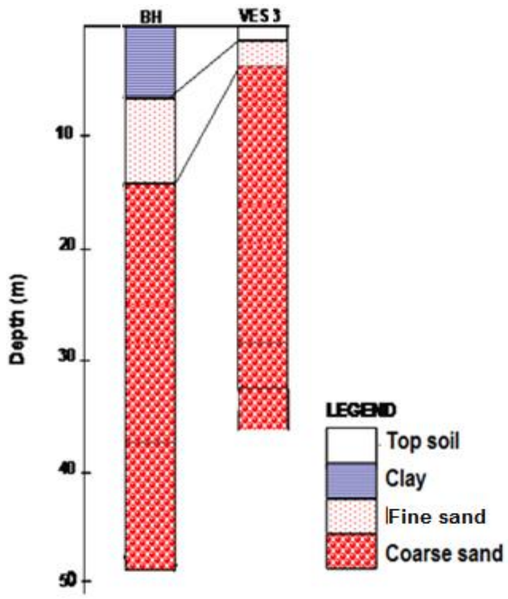

Fig. 2: Correlation of geoelectric section with corresponding borehole lithologic log at Otor-Jeremi

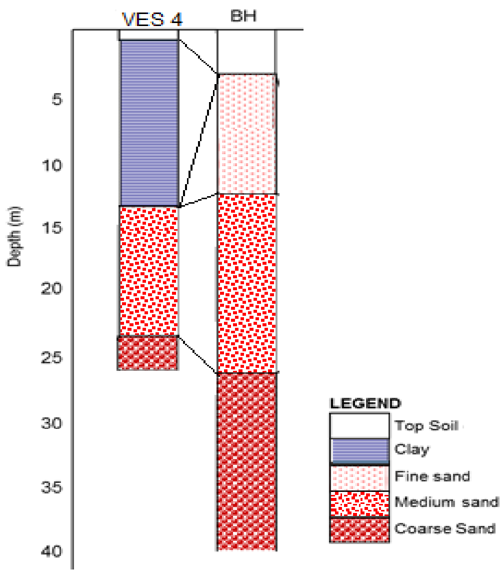

Fig. 3: Correlation of geoelectric section with corresponding borehole lithologic at Otor-Jeremi

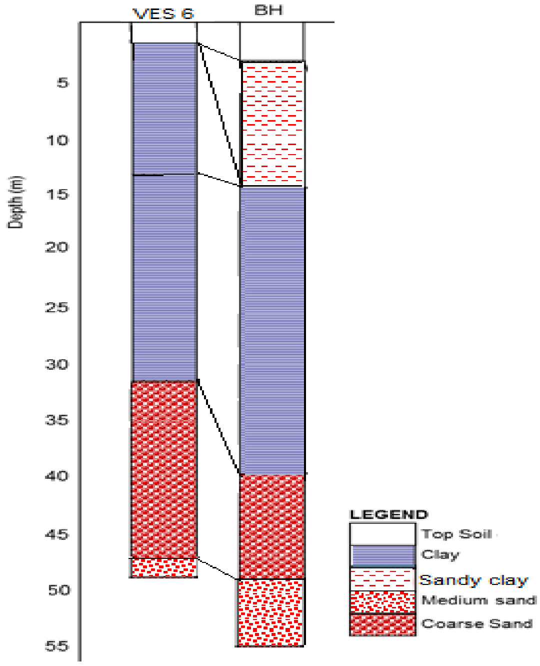

Fig. 4: Correlation of geoelectric section with corresponding borehole lithologic log at Benisede

At Ibusa (location 7), the first layer (sandy clay) did not correlate with the actual lithology (laterite). However, the delineated lithology of the second, third and fifth layers correlated with the actual lithology. At location 8, the second layer (sandy clay) and third layer (sand) were correctly delineated as they correlated with actual lithology. The efficiency of resistivity sounding in delineating lithology at these locations is 70%. The delineated succession at Ibusa (location 9) shows six layers; three layers (first, fourth and sixth layers) were correctly delineated, the second and third layers were partially delineated giving an efficiency of 67%.

At Oleh (locations 10, 11 and 12), the lithology of three out of four layers were correctly delineated; while that of one layer was partially delineated at location 10. The lithology of the second layer (clayey sand) was partially delineated as clay resulting in an efficiency of 88%. Around location 11 & 12, the lithology of two out of three layers was correctly delineated while the lithology of the middle layer was partially delineated at location 11; it was however not delineated at location 12 resulting in an efficiency of 83 and 67 % respectively. The correlation of delineated subsurface lithologies from geoelectric data with actual lithologies at Olomoro indicated an efficiency of 88, 75 and 67% at locations 13, 14 and 15, respectively. At location 13, three out of four lithologies were correctly delineated; two out of four lithologies were correctly delineated at location 14 while the remaining two were partially delineated. Within location 15, the lithology of the last layer was correctly delineated while the lithologies of the two overlying layers were partially delineated.

The efficiency of resistivity sounding in delineating lithology at Uzere (location 16) and Orerokpe (location 17 and 18) is 75, 63 and 88%, respectively. Correlation of geoelectric section with corresponding borehole lithologic logs showed that lithologies of three out of four layers were correctly delineated at location 16 and 18. On the other hand, lithologies of two out of three layers corresponded with those of lithologic logs. At Ekakpamre (location 19), the efficiency of resistivity method in delineating lithology is 75%. Three out of four lithologic units delineated correlated with those of lithologic log except the second layer which was delineated as sand inference from lithologic log (Fig. 5) indicated clay. At location 20 also in Ekakpamre, the efficiency is 67%; delineated geoelectric layers correlates with the lithology of the drillers log except for the second layer which the delineated lithology is clay whereas it was actually sand from the lithologic log (Fig. 6).

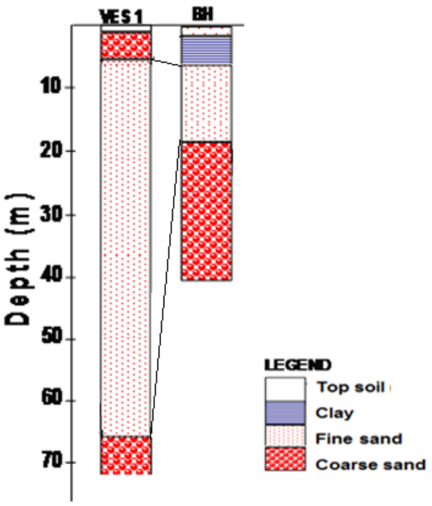

Fig. 5: Correlation of geoelectric section with corresponding borehole lithologic log at Ekakpamre

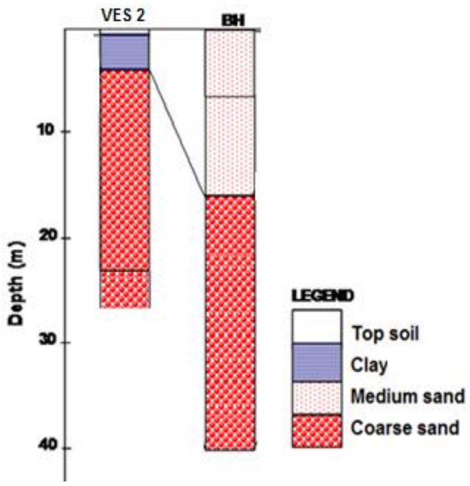

Fig. 6: Correlation of geoelectric section with corresponding borehole lithologic log at Ekakpamre

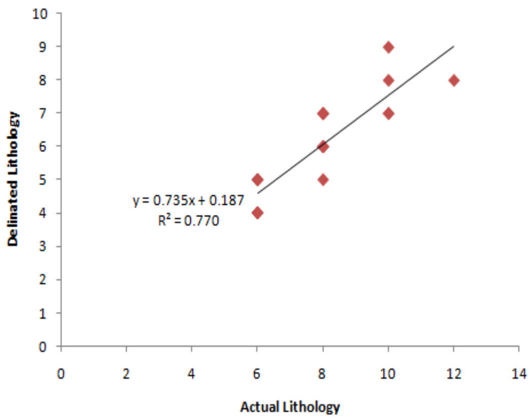

Fig. 7: Correlation of delineated lithologies with actual lithologies

A correlation of delineated lithologies with actual lithologies (Fig. 7) shows strong positive correlation (r^2= 0.77) and overall average efficiency of 77% indicating that resistivity method could be very effective in delineating subsurface lithostratigraphic units in the absence of lithologic log data. The non-correlation/partial agreement between delineated and actual lithologies is due to equivalence.

The findings of this study are in line with observations of Oyinloye and Ademilua (2006) that obtained a high level of average delineative efficiency of 81% and a strong positive correlation between geoelectrically delineated lithology and actual lithstratigraphical sequence. Ohwoghere-Asuma *et al.* (2018) had earlier emphasized the significance of borehole data in providing information on subsurface geology; subsurface geology interpreted from resistivity and VLF-EM was consistent with geologicsection from borehole log data. The presence of clay in the subsurface as indicated by borehole log was correctly delineated by resistivity sounding at location 1 as a low resistivity layer characterized with resistivity value of 92.3 Ωm. Subsurface lithofacies distribution at Koko, Niger Delta was characterized by Ohwoghere–Asuma *et al.* (2019) using electrical resistivity and validating results with lithologiclog. The occurrence of peat at depths of between 49 – 53 m in the subsurface was correctly delineated by resistivity sounding. The results of this study have demonstrated the potential effectiveness of resistivity in delineating lithology of the subsurface.

Conclusion

The results of this study indicates that resistivity method show high efficiency in delineating lithologic units and can be useful for groundwater pre-drilling investigation in areas with very limited on non-existent data to unravel subsurface layers and delineation of suitable aquifers. However, there may be some differences between delineated lithological sequence and actual litholocal sequence and this shows that lithological sequence are not entirely the same as geoelectric layer sequence. This is due to the fact that vertical electrical sounding curve interpretations are basically related to many equivalent models that may be quite different considerably.

Conflict of Interest

Author declares that there is no conflict of interest reported on this work.

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