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GEOELECTRIC/ELECTROMAGNETIC VLF SURVEY FOR GROUNDWATER DEVELOPMENT IN A BASEMENT TERRAIN – A CASE STUDY

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Abstract

A geophysical investigation for groundwater development involving the electrical resistivity and electromagnetic VLF methods was carried out in the premises of the Conference Centre, Obafemi Awolowo University, Ile-Ife, southwestern Nigeria.

The investigation involved three reconnaissance VLF-EM profilings and six vertical electrical soundings (VES). The VLF normal and filtered real component anomalies identify five major geological interfaces suspected to be faults/fractured zones. One of the interfaces coincided with a river channel which is suspected to be structurally controlled.

The geoelectric section prepared from VES interpretation results delineate four subsurface layers which include the topsoil, weathered layer, partly weathered/ fractured basement and the fresh basement. The weathered layer and the partly weathered/ fractured basement constitute the aquifer units. The weathered layer is relatively thin (1.8m - 4.7m) while the partly weathered/fractured basement is significantly thick (15.7m - 67.3m) and extensive with tendency for significant groundwater discharge capacity.

The lithological log from a test borehole at one of the VES stations corroborated geophysically predicted subsurface sequence and its structural disposition. Fractured basement columns were identified at depth ranges of 2.5 - 7m and 12 - 45m within a column of fresh basement rock. The borehole whose aquifer is primarily fractured basement discharges about 2.0 L/s.

Keywords: electromagnetic, electrical resistivity, lithological log, groundwater development.

1. Introduction

Faults, lithological contacts/boundaries, network of joints, fractures/fissures and shear zones are structural features with hydrogeological significance in crystalline basement complex rocks. These geological features deform the basement rocks creating inhomogenieties which in turn enhance groundwater storage and groundwater flow.

Geophysical methods play an increasingly important role in the search for these suitable and productive groundwater reservoirs. Electrical resistivity method has been used routinely in exploration for groundwater. However, several other geophysical methods have been applied successfully either singly or in combination, for prospecting for groundwater resources in varying geologic situations. Olorunniwo and Olorunfemi (1987) used combination of magnetic, electromagnetic (VLF) and electrical resistivity methods to map buried bedrock relief for groundwater exploration in the Precambrian terrain of Ikare, southwestern Nigeria. The electromagnetic (VLF) method has found useful applications in groundwater investigation in basement terrain, most especially as a reconnaissance tool (de Jong *et al*., 1981; de Rooy *et al.,* 1986; Hazell *et al.* 1988; Amadi and Nurudeen 1990; Olayinka 1990; Olorunfemi *et al.,* 1995). Olorunfemi *et al*. (2001) applied the spontaneous potential (SP) and electrical resistivity to understand the nature and groundwater development feasibility of a suspected spring in Ajegunle-Igoba, Akure.

In this paper, we present the results of the application of electromagnetic (EM) and electrical resistivity methods in the delineation of favourable hydrogeophysical regime for productive aquifers in the premises of the Conference Centre, Obafemi Awolowo University, Ile-Ife, southwestern Nigeria (Fig. 1).

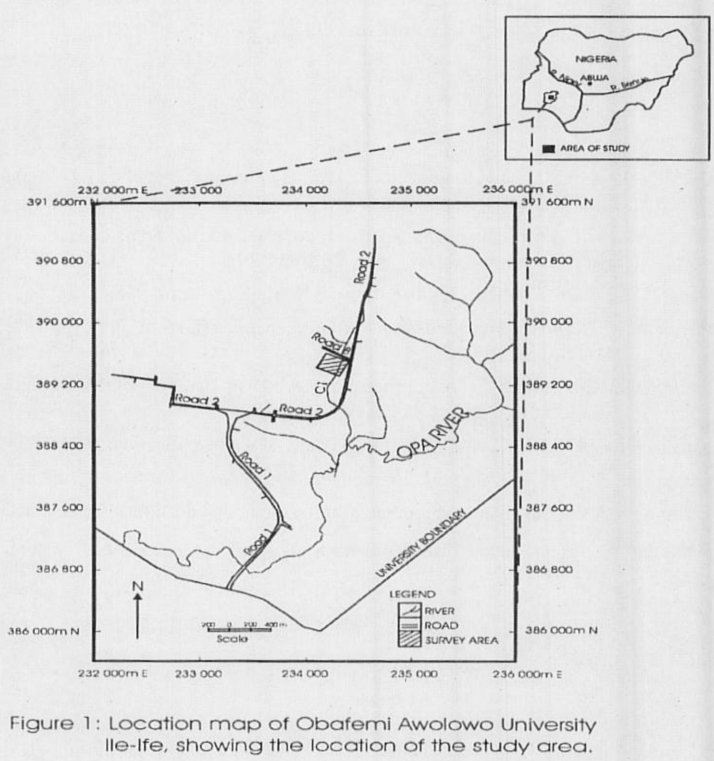

Figure 1: Location map of Obafemi Awolowo University Ile-Ife, showing the location of the study area.

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The geophysical investigations were carried out in the target area to delineate the subsurface layers beneath the sounding stations and determine their geoelectric parameters. It was also aimed at identifying the aquifer unit, determining its depth and lateral extent and identifying possible subsurface fault/fracture planes in the study area. The field layout of the geophysical traverses and measurement stations are shown in Figure 2.

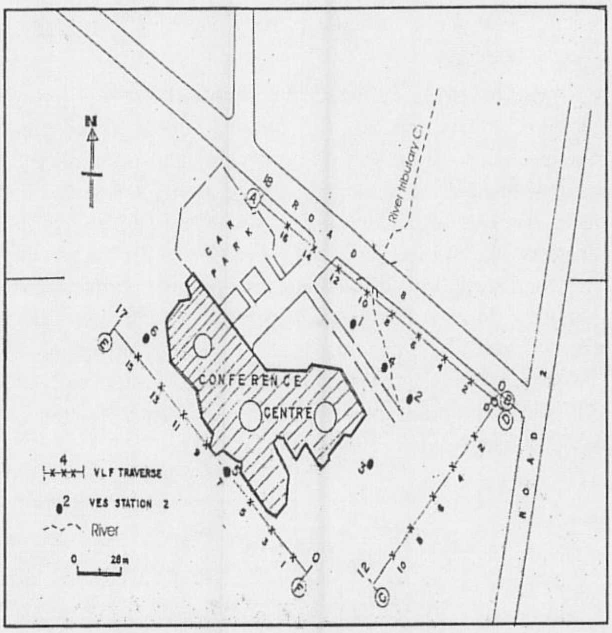


Figure 2: Geophysical survey map showing the field layout of the geophysical traverses

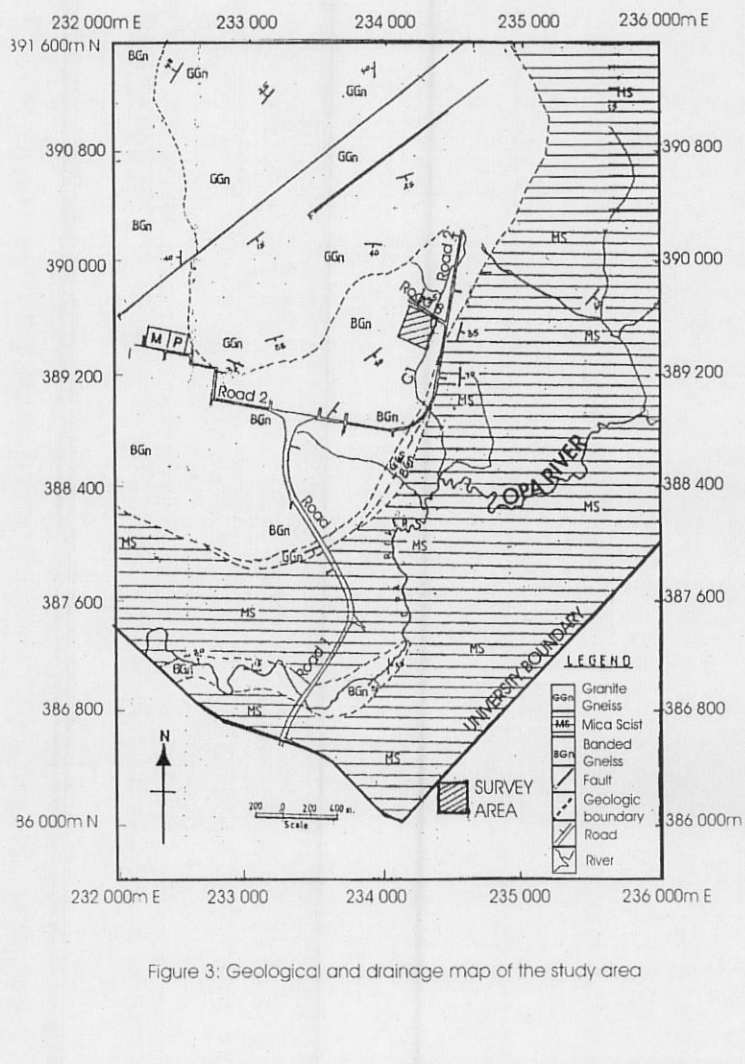


Figure 3: Geological and drainage map of the study area

2. Geomorphology and geology of the study area

The survey site is located on a lowland area east of Hill 1 on the Obafemi Awolowo University Campus. The terrain of the survey site is relatively flat. It slopes gently south-eastward into a river valley. The topographic elevation is less than 300m above sea level.

The site is underlain by the Precambrian Basement Complex rock of Nigeria. The main geological unit in the area is the grey or banded gneiss. The grey or banded gneiss rock belongs to the migmatic-gneiss complex which constitutes one of the major rock units of the Precambrian Basement of southwestern Nigeria. Figure 3 shows the geological and the surface drainage map of the study area. The main river in this area is the Opa river whose perennial tributary C1 flows North-South through the study area.

In a basement complex terrain, groundwater is confined within weathered layer and or fractured/jointed or sheared basement columns. Groundwater yield in such geological environment is a complex function of the weathered layer thickness, its clay content and the density of fractures.

The geophysical survey

Electromagnetic VLF survey

The electromagnetic VLF (Very Low Frequency) geophysical method provides a quick and powerful tool for the study of shallow conducting lineament features in the near-surface earth (Telford *et al.,* 1977). The method is based on measurement of the secondary magnetic field induced in local conductors by primary EM fields generated by powerful naval radio transmitters in the very low frequency range (15-25kHz). The instrument employed for the VLF survey was the EM-16 (VLF-EM) which measures the in-phase and quadrature components of the induced vertical magnetic field as a percentage of the horizontal primary field (GEONICS 1979). These measurements are equivalent respectively to the tangent of the tilt angle and the ellipticity of the polarization ellipse. The main fracture directions in this locality is approximately north-south, which approximate local directions to GBR (Rugby, England), FUO (Bordeaux, France) and NAA (Cutler, Maine) VLF stations. At the time of the survey, GBR (Rugby, England) was well received.

The VLF measurements were made along three traverses with station intervals of 10m (Fig. 2). The EM data are presented as profiles. The real VLF data were converted to filtered real by applying a filtering operator **Q** which transforms true VLF anomaly inflections to peak positive anomalies and false VLF anomaly inflections to peak negative anomalies. The filter operator is given by

$$\mathbf{Q} = [(\theta_3+\theta_4) - (\theta_1+\theta_2)] \quad (1)$$

where **Q** is the filter operator and θ_1, θ_2, θ_3 and θ_4 are the readings of the measured real at stations 1, 2, 3 and 4. Figures 4, 5 and 6 show the real and filtered real VLF anomaly curves obtained along traverses A-B, C-D and E-F respectively.

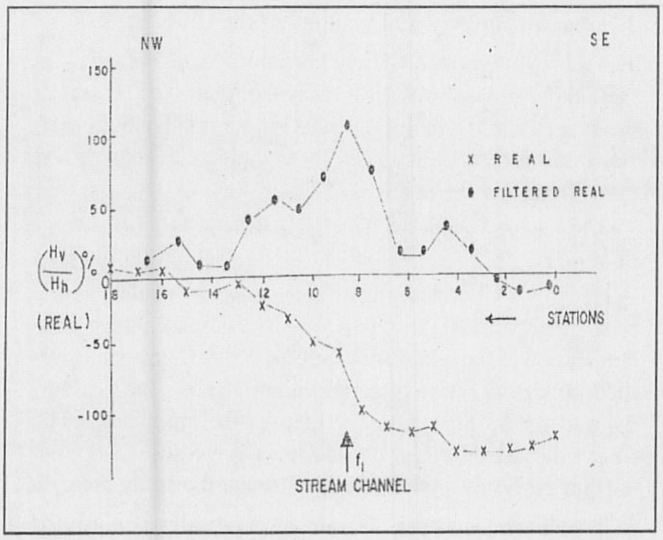


Figure 4: VLF anomaly curve (real component) along traverses A - B

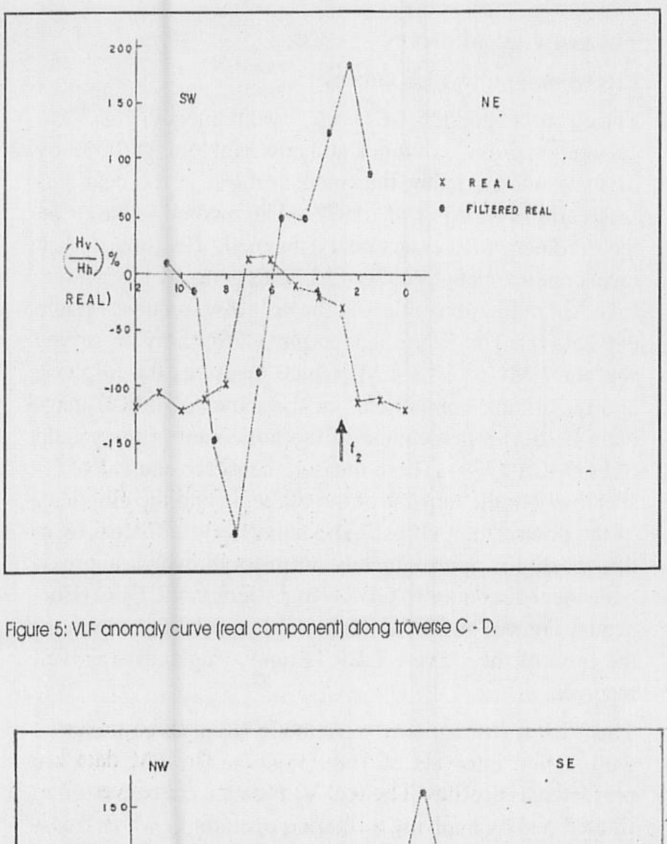


Figure 5: VLF anomaly curve (real component) along traverse C - D.

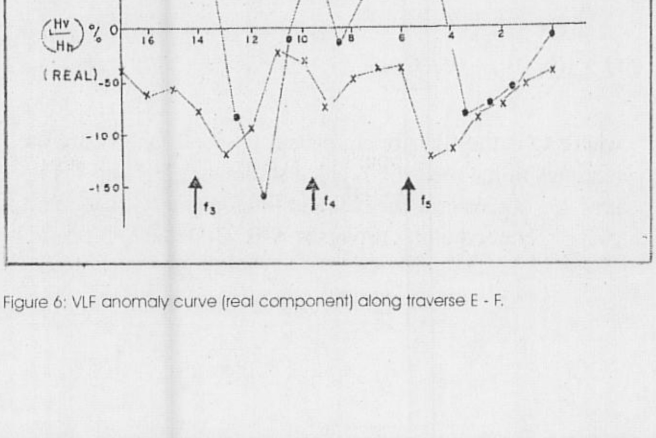


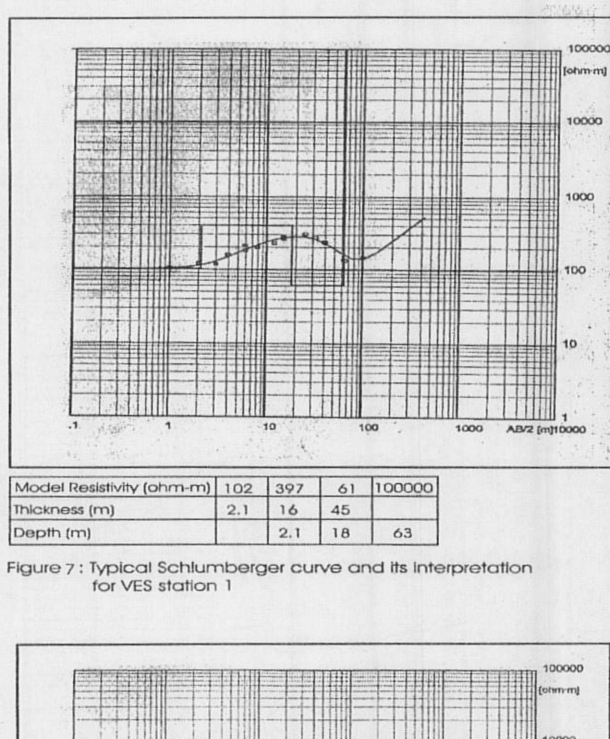
Figure 6: VLF anomaly curve (real component) along traverse E - F.

The imaginary component of the secondary electromagnetic field was noisy and therefore unreliable for qualitative interpretation.

Electrical Resistivity Survey

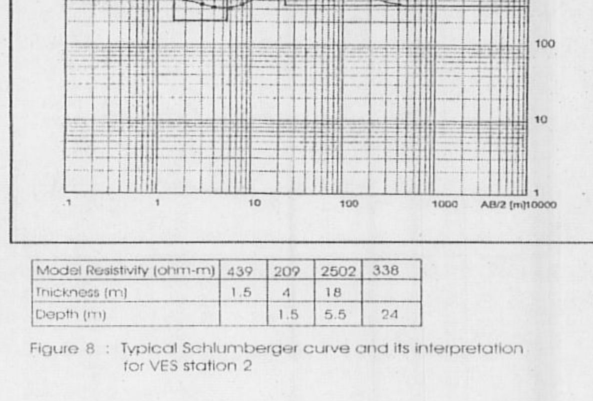
The electrical resistivity method involves passage of current into the ground through two current electrodes while the resulting potential difference is measured between another pair of potential electrodes which may or may not be located within the current electrode pair, depending on the electrode array.

The present survey utilized the Vertical Electrical Sounding (VES) technique. Six VES stations were occupied within the premises of the survey area using the Schlumberger array with electrode spacings (AB/2) varying from 1 to 100m (Fig. 2). The VES data are presented as depth sounding curves. Quantitative (1-D) interpretation of the VES curves involved partial curve matching and computer iteration techniques. Figures 7, 8 and 9 show typical Schlumberger curves from the study area and their interpretation using W-Geosoft's WinSev 5.1 resisitivity interpretation software. The depth sounding interpretation results are presented as geoelectric sections (Figs. 10 and 11).



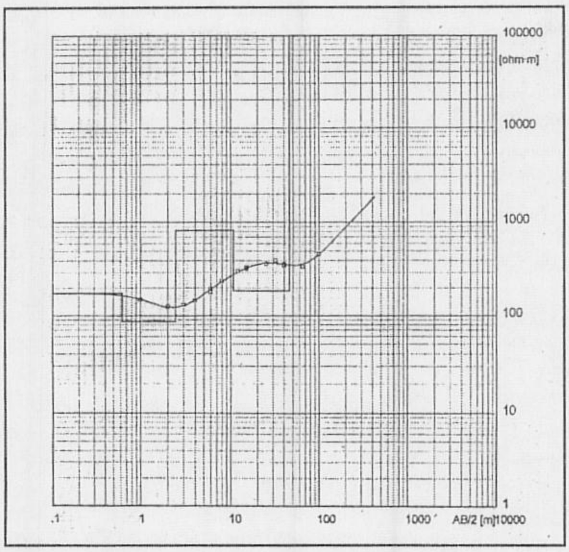
Model Resistivity (ohm-m)	102	397	61	100000
Thickness (m)	2.1	16	45	
Depth (m)		2.1	18	63

Figure 7 : Typical Schlumberger curve and its interpretation for VES station 1



Model Resistivity (ohm-m)	439	209	2502	338
Thickness (m)	1.5	4	18	
Depth (m)		1.5	5.5	24

Figure 8 : Typical Schlumberger curve and its interpretation for VES station 2



Model Resistivity (ohm-m)	175	86	819	187	100000
Thickness (m)	0.63	1.8	8.3	35	
Depth (m)		0.63	2.4	11	46

Figure 9 : Typical Schlumberger curve and its interpretation for VES station 4.

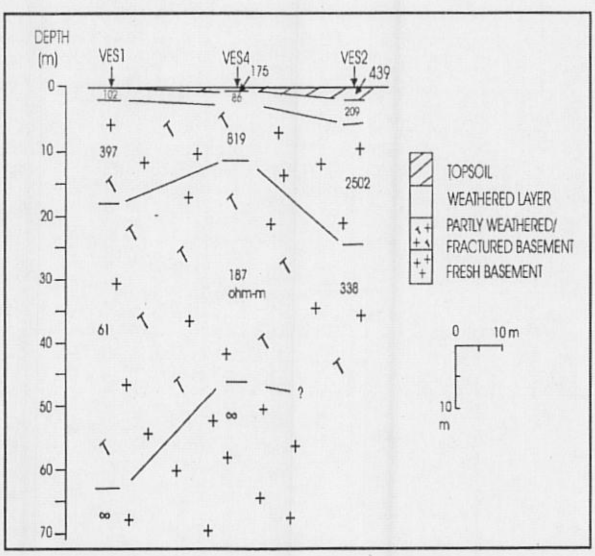


Figure 10: Geoelectric section relating VES stations 1, 4 and 2.

3. Results and Discussion

EM profiles

Geological interfaces ($f_1 - f_5$) were delineated using characteristic features of coincident inflections on real component anomaly curves and positive peaks of filtered real anomaly curves (ABEM, 1990; Olorunfemi *et. al.*, 1997) (see Figs. 4, 5 and 6). Interface f_1 coincides with the river course (compare Figs. 2 and 4). This is strongly indicative of structurally (fault) controlled river course. The other interfaces ($f_2 - f_5$) are near-surface/ sub-surface fractures in the basement complex rock. When such linear features are water saturated, they constitute good aquifer units.

Geoelectric Sections

The depth sounding interpretation results are presented as geoelectric sections (Figs.10 and 11). Four (4) subsurface layers were delineated as shown below:

1st Layer: Topsoil of sandy clay/clayey sand.
Resistivity : 102-469 ohm-m; thickness: 0.6-1.5m

2nd Layer: Weathered Layer. This layer is composed of clay/sandy clay/clayey sand
Resistivity : 86-287 ohm-m; thickness: 1.8-4.7m

3rd Layer: Partly weathered/Fractured Basement.
Resistivity: 61-338 ohm-m; thickness: 15.7- 67.3m (where the bottom of the layer was delineated)

4th Layer: Fresh Basement.
Resistivity: 819 - ∞ ohm-m; depth to rock head: 0.6-5.8m

The above shows that the survey area is characterized by a relatively thin (< 10m) weathered layer with limited hydrogeological significance. The partly weathered/fractured basement unit is however significantly thick and extensive with tendency for large storage capacity and significant groundwater yielding capacity.

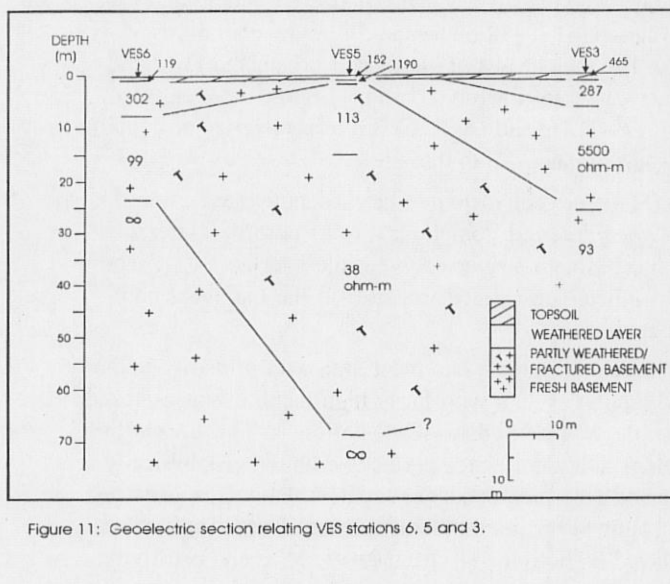


Figure 11: Geoelectric section relating VES stations 6, 5 and 3.

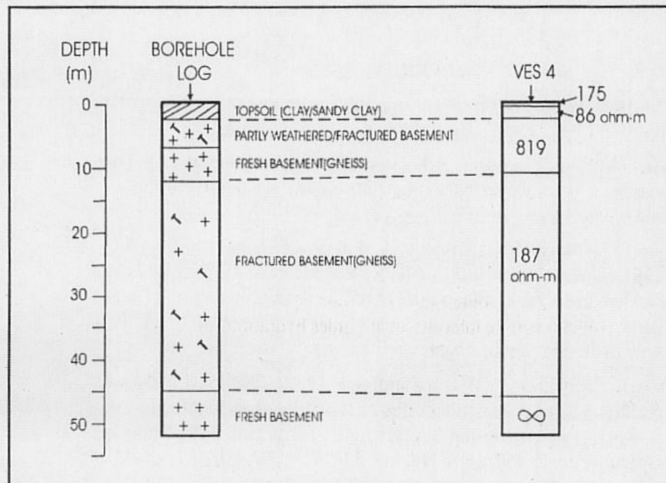


Figure 12: Correlation of borehole lithological log with vertical electrical sounding (VES 4) interpretation results.

The basement rock as inferred from the electromagnetic VLF profiles and geoelectric sections is fractured beneath VES station 4 at depth ranges 2.5 - 7m and 12.0 - 45.0m. The fractured basement column is confined by an estimated 5m thick fresh basement column. On the basis of our result, a water borehole was recommended for drilling at VES station 4. Figure 12 shows a comparison of obtained geophysical results and drill-hole log. The VES interpretation result predicted depth to fresh basement bedrock to be 46m whilst drilling result confirmed 45m showing very good correlation. The test borehole was productive with groundwater yield of about 2.0 L/s which indicates adequate recharge. The static water level remains at about 1.2m.

The borehole log corroborated predictions from both VLF and VES interpretation results. It also confirms an earlier inference that the adjoining stream is structurally (fault) controlled.

4. Conclusions

Four major subsurface layers were delineated from the VES interpretation results. These include the topsoil, weathered layer, partly weathered/fractured basement and the fresh basement with resistivity ranges of 102 – 469 ohm-m, 86 – 287 ohm-m, 61 – 338 ohm-m and 819 - ∞ ohm-m respectively. The thicknesses of the topsoil, weathered layer and partly weathered/ fractured basement range between 0.6 – 1.5m, 1.8 – 4.7m and 15.7 – 67.3m respectively. The depth to rockhead ranges from 0.6 – 5.8m.

Five (5) major geological interfaces identified as f_1, f_2, f_3, f_4 and f_5 were inferred from the EM (VLF) profiles. Interface f_1 coincided with a river course while interfaces f_1 –f_5 are near-surface/ sub-surface fractures in the basement complex area.

The above indicates a basement area with primarily fractured aquifer system with fairly high depth extent. A test borehole was drilled at VES station 4. The borehole lithological log correlated perfectly with the geophysically predicted geological sequence and its structural disposition. The confined fractured basement column was identified as predicted by both the electromagnetic VLF and resistivity depth sounding surveys.

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