ELECTROMAGNETIC PROFILING AND RESISTIVITY SOUNDINGS IN GROUNDWATER INVESTIGATIONS NEAR EGBEDA-KABBA, KWARA STATE

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ABSTRACT

As part of a borehole siting programme for rural water supply in a Precambrian crystalline basement terrain, 36 Offset - Wenner electrical soundings and about 4.5 line-kilometres of ground conductivity profiling with a Geonics EM34-3 equipment were made near Egbeda-Kabba, Kwara State, Nigeria.

The EM34-3 measurements provided a rapid reconnaissance tool in identifying high conductivity anomalies thought to be due to deep weathering and/or bedrock fissuring. The apparent conductivities are generally less than 50 mmho m^{-1}. A quantitative interpretation of the vertical sounding data indicated that the resistivity of the weathered zone varies over a wide range, from about 10 to 200 ohm.m, and that the overburden is generally less than 40m thick.

Three abstraction wells, each having a yield of about $1 ls^{-1}$, were drilled at deeply weathered sites (depth to bedrock > 20m) identified from the surface geophysical measurements.

INTRODUCTION

Crystalline beasement complex rocks are relatively impermeable and have no storage capacity. Consequently, the groundwater resource in such terrains, which are widespread in Africa, is limited. Nonetheless, large numbers of water wells have been successfully developed in these areas (Foster 1984). Aquifers are commonly restricted to features produced by weathering and tectonic processes (Enslin 1961). To ensure maximum and perennial yields it is essential that a borehole be located where it can penetrate the greatest possible thickness of both the regolith and the fractured zone, before hitting the fresh bedrock. A ground geophysical survey is often carried out to locate the groundwater aquifers accurately.

Two of the most commonly used geophysical techniques for groundwater exploration are electromagnetic (EM) profiling and resistivity soundings. The aim of EM surveys is the identification of high conductivity anomalies, normally thought to be due to deep weathering. Such anomalies are often further investigated by soundings in order to provide a more quantitative information on the geoelectrical profile through the weathered zone as an aid in siting borehole (Palacky et al. 1981, Carruthers 1985).

The theme of this paper is the presentation of the results of an integrated geophysical survey, involving EM profiling and resistivity soundings, carried out in a basement area of Nigeria. The survey was aimed at locating sites suitable for the drilling of abstraction wells.

STUDY AREA

The survey area, Egbeda Kabba (6° 07'E; 7° 46'N), is an agricultural village in Kwara State situated approximately 240km southeast of Ilorin (Fig 1). The projected 1995 population is 2800 with an expected water demand of 3 ls^{-1} abstracted over a 14 hour daily pumping period (Biwater 1987).

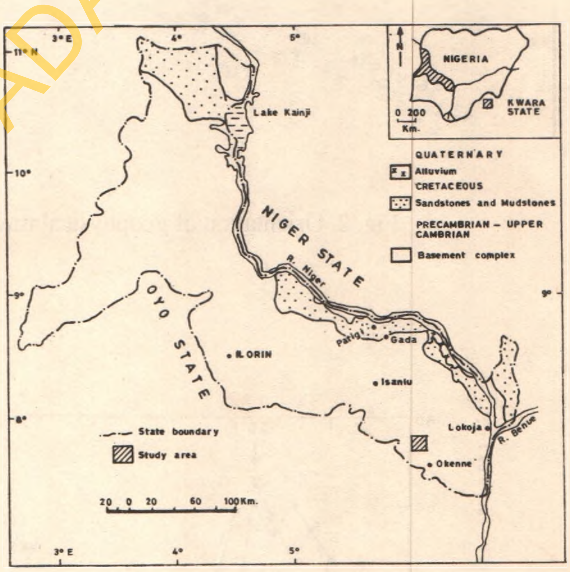

Fig. 1. Generalised geological map of Kwara State showing the location of survey area

The village lies within the Nigerian Precambrian Basement Complex. The geological survey map (Lokoja Sheet 62) suggests that the basement complex in this area comprises migmatised biotite gneisses intruded by granites and granodiorites. However, there are no rock exposures, making any detailed surface geological mapping very difficult.

The main surface sources of water in the survey area are seasonal. As at August 1981 when a feasibility study for the improvement of water supply to Egbeda-Kabba village

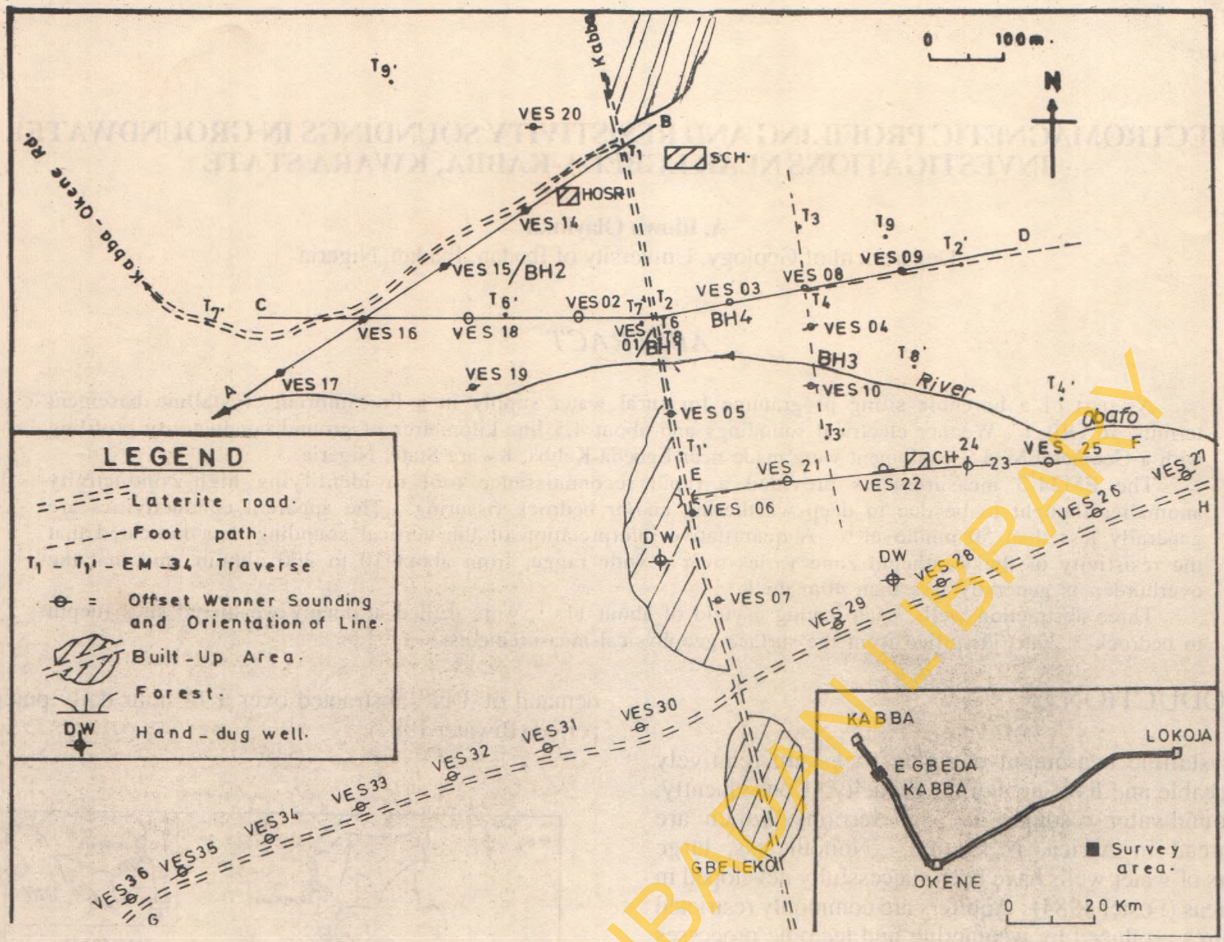

Fig. 2. Orientation of geophysical traverses, Egbeda-Kabba survey area

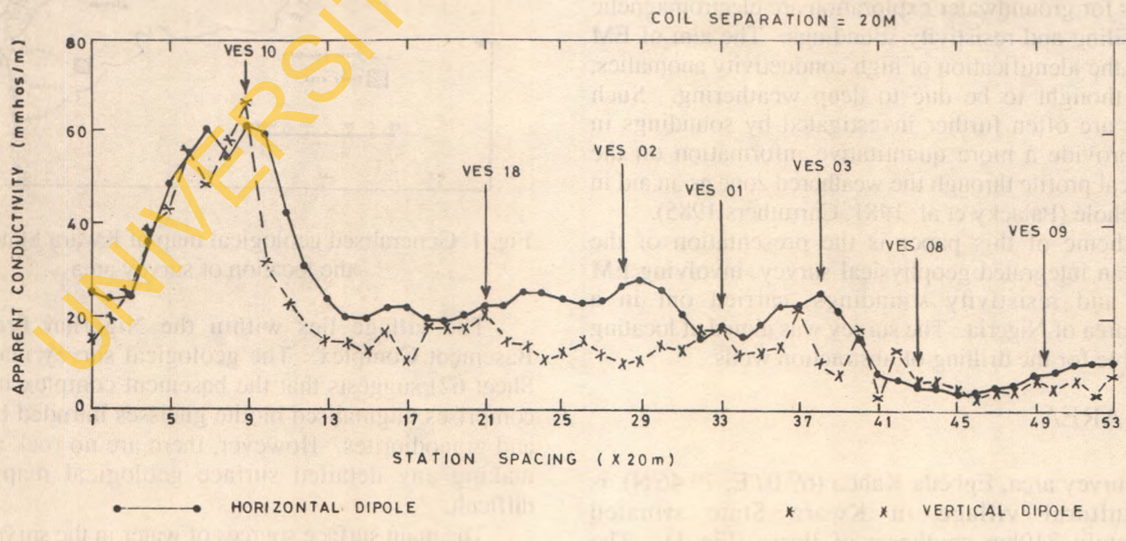

Fig. 3. EM34-3 conductivity profile along traverse C-D. Coil separation was 20 m

was carried out (Babtie et al. 1982) there were eleven dug wells of which only three were non-seasonal. The average depth to water in the wells is about 6m.

FIELD MEASUREMENTS

An earlier reconnaissance geophysical survey of the village (Upton 1984) suggested the possibility of a W-E trending low-resistivity anomaly probably indicative of deep weathering, across the Egbeda Kabba-Gbeleko road (Between soundings VES 02 and VES 08 in Fig 2). The present survey, carried out during August and September 1985, was conducted as a detailed follow-up investigation to assess the viability of tapping the groundwater resources.

Initially, the survey was concentrated around the suspected resisitivity low, and later extended beyond the limits of the village across the River Obofo, to the neighbouring Gbeleko village. This was in order to have a fairly dense coverage of the geophysical survey. However, it was not possible to cover parts of the lower western half of the area due to thick vegetation.

In all, nine EM34-3 profiles were made (McNeill 1980), using a 20m coil separation over a total spread of about 4.5 line kilometres. Readings were taken for both the horizontal and the vertical coil configurations, with a maximum depth of investigation of about 15m and 30m, respectively. Thirty-Six, Offset-Wenner soundings (Barker 1981) were also conducted, with a maximum inter-electrode separation of a = 128m. An ABEM SAS Terrameter was used for resistance measurements. To reduce contact difficulties, especially at large electrode spacings where low resistances are measured, it became necessary to moisten the ground around the eltrode with large quantities of water. Similarly, double electrodes were used at the outer two electrode positions. The orientations of the geophysical traverses are shown in Fig 2.

ANALYSIS OF GEOPHYSICAL DATA

Due to the sensitivity of EM systems to near-surface conductivity variations, especially where highly conductive regoliths are present, and since the horizontal and the vertical coil systems respond differently to near-surface changes in conductivity (McNeill 1980) only a qualitative interpretation of the ground conductivity profiling measurements had been carried out. The high conductivity anomalies, which might be related to the occurrence of groundwater, were often further investigated by electrical soundings, in order to provide a more quantitative assessment of the subsurface geology as an aid in borehole sitting. The Offset-Wenner array (Barker 1981) was employed, this being an extremely fast technique of acquiring sounding data.

It has been suggested (Zohdy 1969, Worthington 1977) that where a conductive regolith overlies a highly resistive bedrock the total longitudinal conductances, S, is a good indication of the bedrock topography. For the Wenner array and a resistive basement, Keller and Frischknecht (1966) have shown that

$$S = 2 \log_e 2 \frac{a}{\rho_a} \qquad (1)$$

where ρ_a is the apparent resistivity measured at a very large spacing a. The total longitudinal conductances of all the layers above the bedrock at each sounding location have been calculated from equation 1, with a = 128m.

A more quantitative field interpretation of the sounding data was achieved by partial curve-maching using 2-layer master curves and auxilliary charts. Iterative computer-checking of the accuracy of the solution was later carried out by calculating a theoretical sounding corresponding to this model (Ghosh 1971). The program for this was run on an Epson HX-20 portable computer. The final stage of the sounding interpretation involved the use of an automatic inversion program (Koefoed 1979). The algorithm was modified by the author to incorporate interactive graphical facilities, and was implemented on the Honeywell DPS S/70 computer at the University of Birmingham. The results show that in most instances the quality of the field interpretation was good.

RESULTS AND INTERPRETATIONS

In general, the EM34 conductivities vary between 10 and 30 mmho m^{-1}. There are some anomalous high values tentatively interpreted as being due to either a clayey regolith or deep weathering. Typical traverse results, made along line C-D, are shown in Fig 3.

The longitudinal conductances are generally less than 0.5 mho. They are particularly low, at less than 0.3 mho, along profile E-F (Fig 4c). This is perhaps owing to a relatively thin regolith. The strong high of 1.34 mho along profiles A-B and C-D (Figs 4a and 4b) also correlates with the high EM34 conductivity anomaly in Fig 3. A quantitative interpretation of VES 16 made at the location of this animaly indicates a very clayey regolith on account of the low resistivity of 9 ohm.m for the prebasement layer (Fig 5).

The soundings (Figs 5-8) commonly show a sequence comprising three layers which are considered to represent the soil layer whose resistivity may exceed 1000 ohm-m, especially when it is dry, indurated or lateritic; the weathered layer with a resistivity varying between 10 and 200 ohm-m; and the infinitely resistive bedrock. The reflection coefficient, K, at the base of the weathered zone typically exceeds 0.9.

The probable geological sequences along some of the traverses, as inferred from the geoelectrical results, are presented in Fig 9. There are large variations in both the thickness and the resistivity of the weathered layer. The maximum development of regolith is probably less than 40m. It is likely that the bedrock is faulted in places.

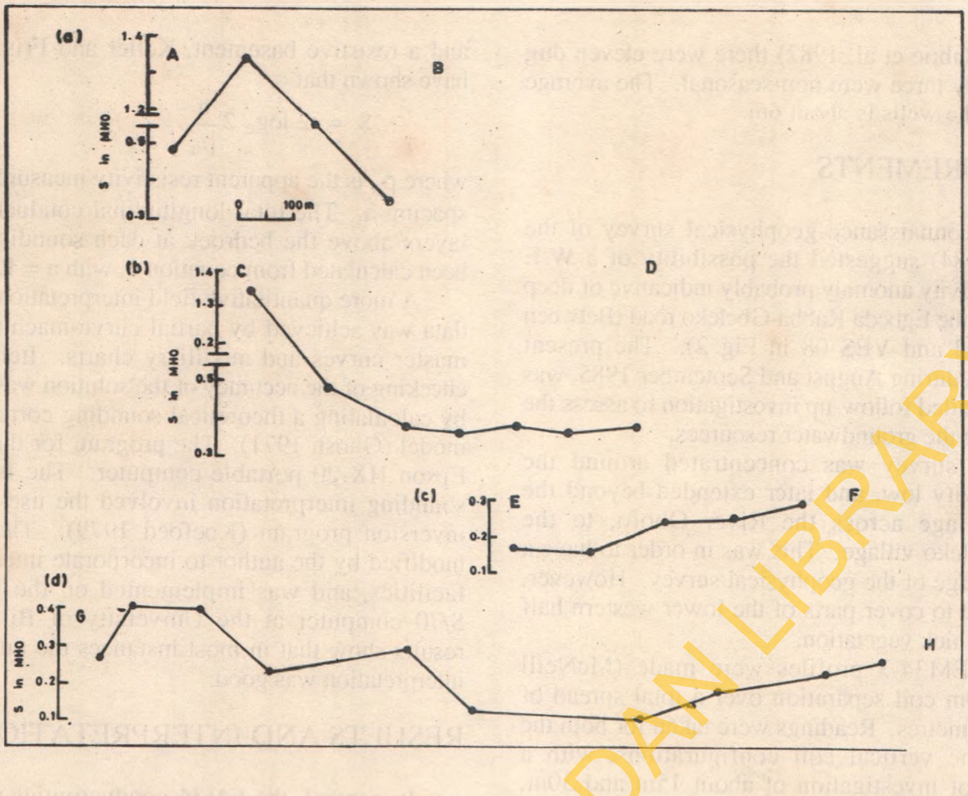

Fig. 4. Total longitudinal conductances profiles. (a) Trasverse A-B, (b) Traverse C-D, (c) Traverse E-F, (d) Traverse G-H (See Fig. 2 for orientation of traverses)

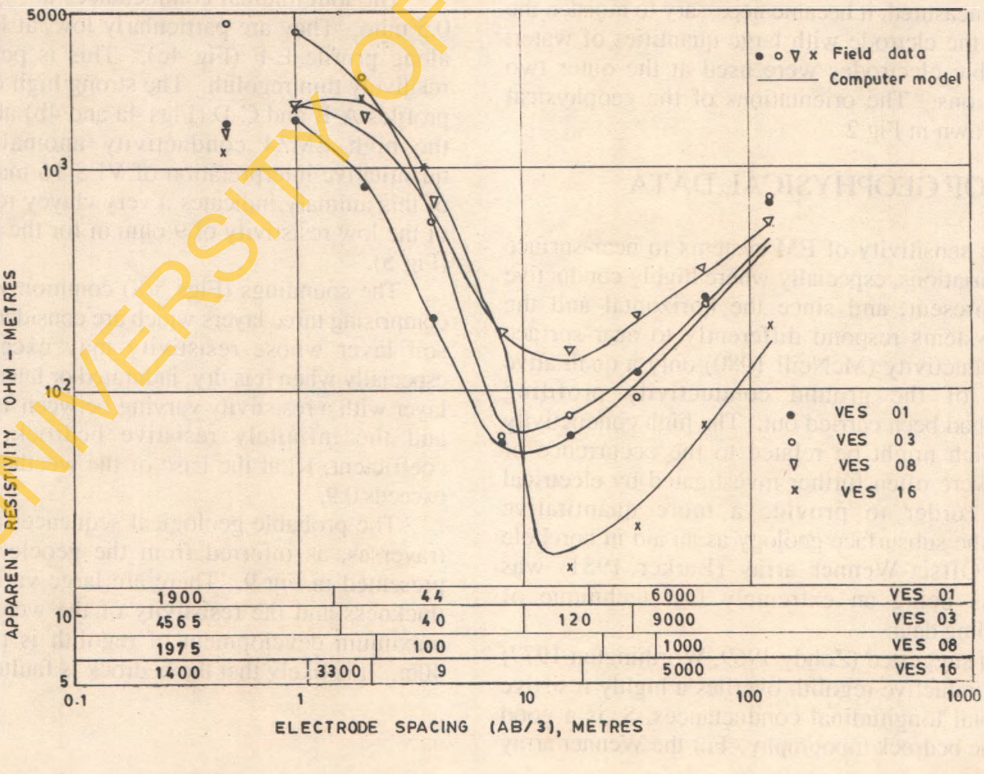

Fig. 5. Quantitative interpretation of typical Offset Wenner soundings along traverse C-D. Values inside the bars represent layer resistivities in ohm. m.

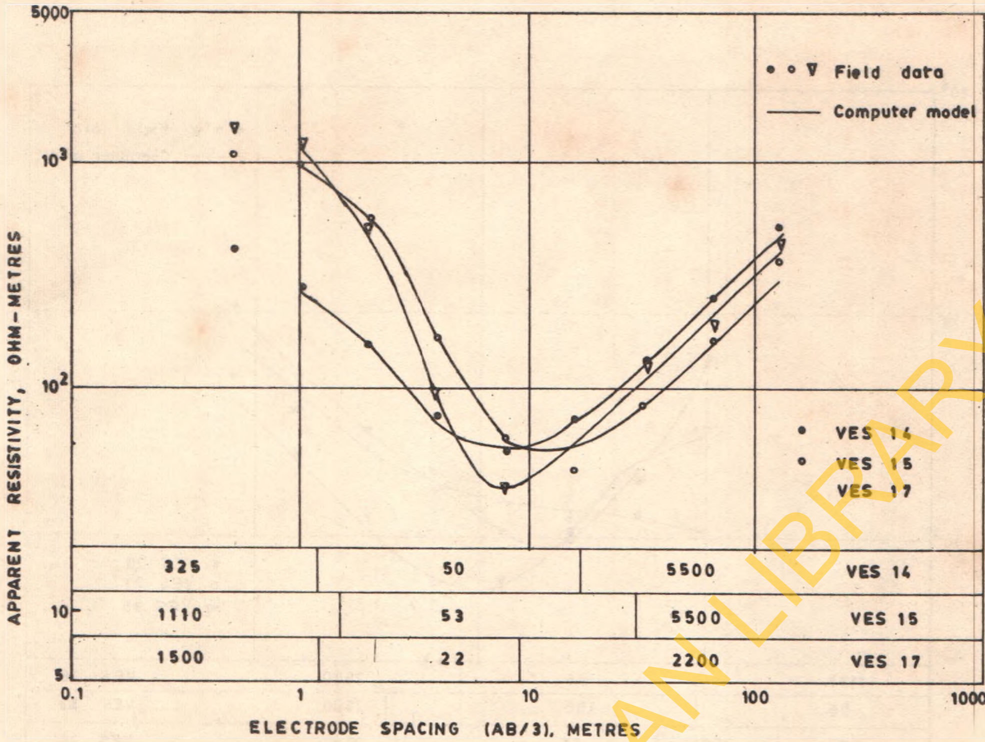

Fig. 6. Offset Wenner Soundings along traverse A-B.

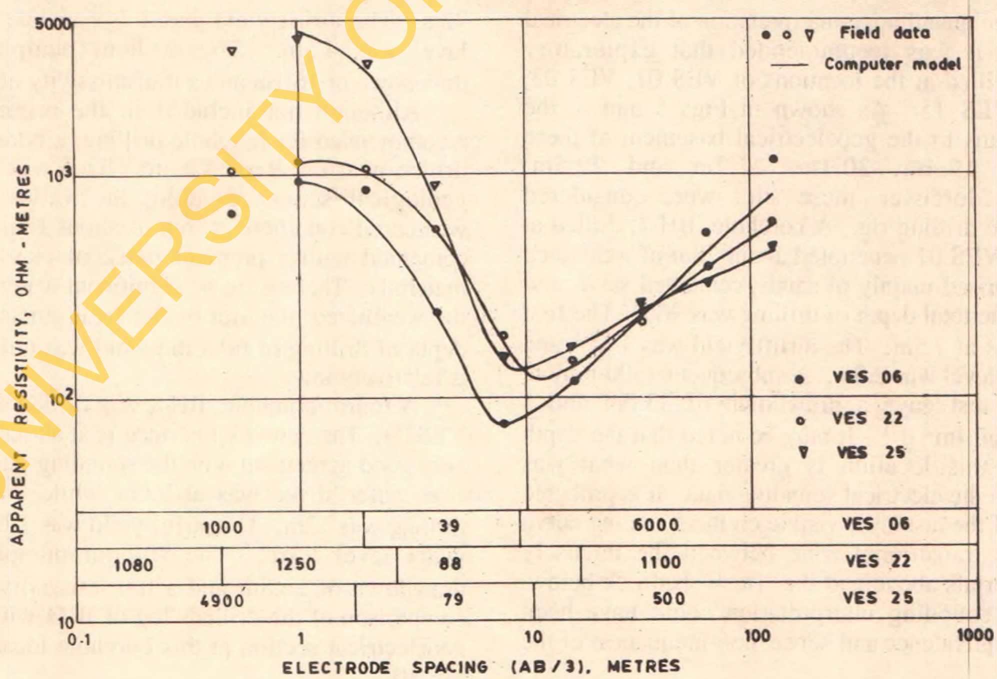

Fig. 7. Typical Offset Wenner soundings along traverse E-F.

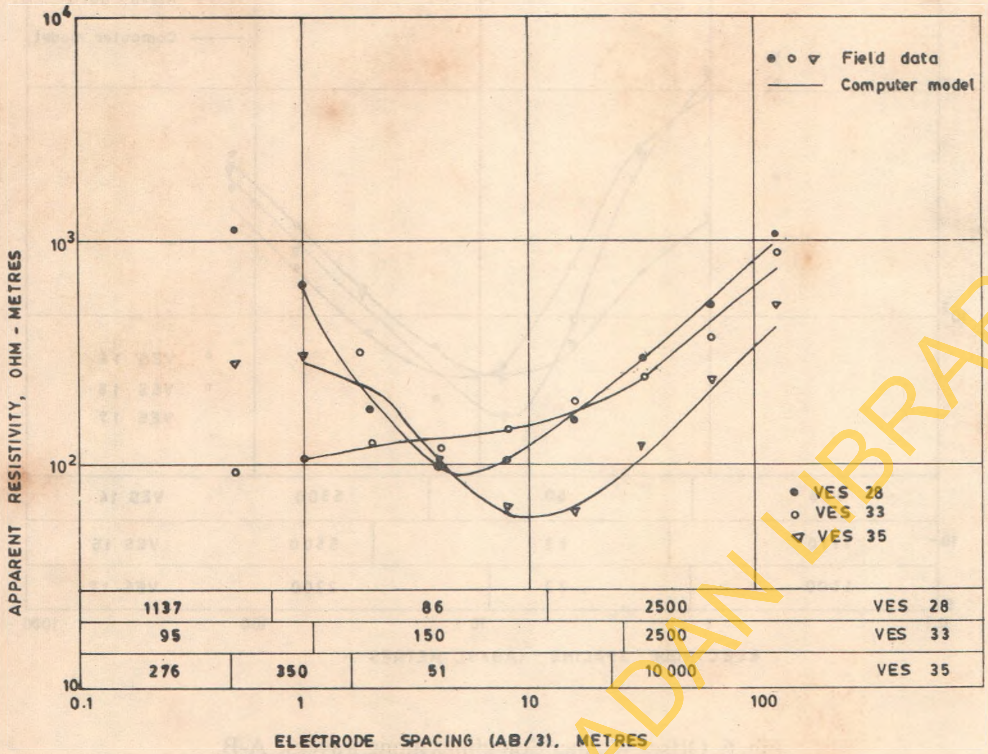

Fig. 8. Typical Offset Wenner soundings along traverse G-H

Integration of geophysical and hydrogeological data

Based on the quantitative interpretation of the electrical sounding data it was recommended that exploratory boreholes be drilled at the locations of VES 01, VES 03, VES 08 and VES 15. As shown in Figs 5 and 6, the interpreted depths to the geoelectrical basement at these locations are 19.4m, 30.1m, 22.2m and 29.5m, respectively. Moreover, these sites were considered accessible to the drilling rig. A borehole, BH 1, drilled at the location of VES 01 penetrated about 28m of weathered basement comprised mainly of sands, cemented sands and sandy clays. The total depth of drilling was 96m. The first water strike was at 7.5m. The airlift yield was 1 ls^{-1} and the static water level was 2.0m. A subsequent 1300-minute long pumping test gave a drawdown of 33.0m and a transmissivity of $4m^2\ d^{-1}$. It may be noted that the depth to bedrock at this location is greater than what was interpreted from the electrical sounding data. It is probable that a portion of the last layer visible on the sounding curve lies within the transitional zone between the intensely weathered materials above and the "fresh" bedrock below. Moreover, the sounding interpretation could have been influenced by equivalence and hence, non-uniqueness of the solution.

A borehole, BH2, drilled on the position of VES 15 penetrated a geological sequence similar to that in BH1. Its lithology shows evidence of bedrock fracturing. The first water strike was at 13.2m and the total depth of drilling was 72m. The airlift yield was 1 ls^{-1} while the static water level was 4.5m. The 50-hour pumping test gave a drawdown of 16.1m and a transmissivity of 6 $m^2\ d^{-1}$.

Although not included in the original list of sites recommended for borehole drilling, a borehole (BH3) was drilled near the River Obofo. This was to ascertain the geological sequence along the valley bottom. The weathered zone here is thin at about 13m and was highly cemented with a preponderance of clay and sandy clay materials. There were no significant water strikes in either the weathered material or the fresh gneiss. After a total depth of drilling of 60m the yield was only 0.5 ls^{-1} which is relatively low.

A fourth borehole, BH4, was drilled at the location of VES 03. The bedrock interface is at about 29m which is in very good agreement with the sounding interpretation. The first water strike was at 9.0m while the total depth of drilling was 72m. The airlift yield was 1 ls^{-1} and the static water level 1.2m. The 70-hour pumping test gave a drawdown of 26.8m and a transmissivity of $3m^2\ d^{-1}$. A comparison of the driller's log of BH4 with the interpreted geoelectrical section at this borehole location is shown in Fig 10.

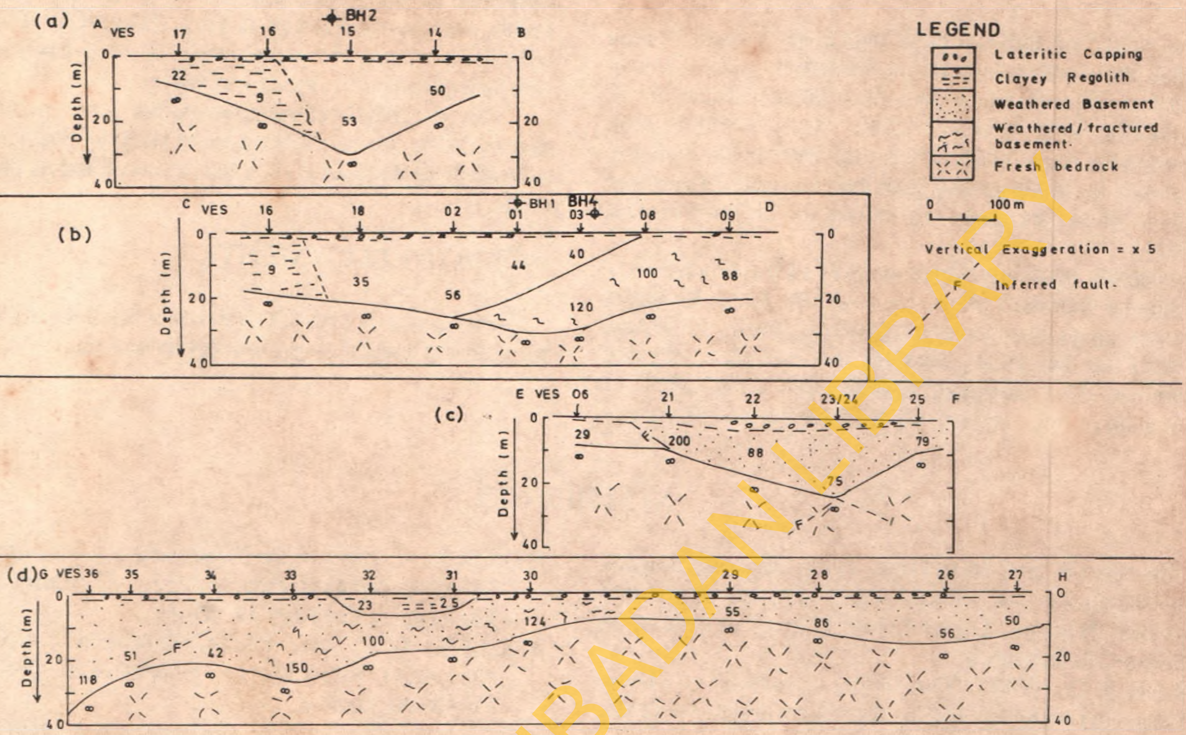

Fig. 9. Probable geological sequences along selected profiles: (a) traverse A-B, (b) traverse C-D, (c) traverse E-F, (d) traverse G-H

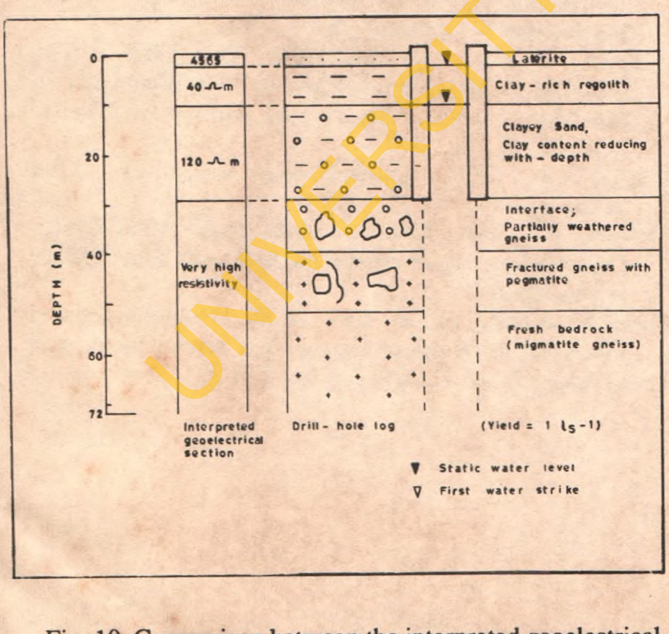

Fig. 10. Comparison between the interpreted geoelectrical section (VES 03) and the borehole lithological section at the site of BH4.

Three of the four drilled holes, namely BH1, BH2 and BH4, were completed as production wells as their yields were considered good in the light of expereiences from other basement areas (Clark 1985, Jones 1985). Borehole BH3 was abandoned. Since the combined yield of the three production wells was considered adequate to meet the projected water demand of the village no confirmatory drilling was thought necessary at some of the other promising sites where deep weathering and/or bedrock fracturing are also expected.

A comparison of the longitudinal conductance profile (Fig 4) with the probable geological sections (Fig 9) shows that, in general, there is a correlation between large depths to bedrock and high conductances. An obvious exception, however, is the clayey, relatively thin regolith towards the west (Fig 4a). Since the longitudinal conductances are indicative of the depth to the geoelectrical basement, it is to be expected that, all other things being equal, areas of high conductance should be highly promising in terms of siting abstraction wells.

The relatively poorer results from the drilling of BH3 highlights the need for caution in siting boreholes based purely on logistical reasons. The three boreholes sited on topographically higher grounds gave higher yields than the one sited at a valley bottom nearby. In particular, the borehole at the valley bottom gave a much lower transmissivity at $0.5m^2 d^{-1}$. It is probable that there is no hydraulic continuity between the valley bottom and the higher ground.

CONCLUSION

The sounding and borehole data from Egbeda-Kabba show that the depth to bedrock in this area is generally less than 40m. The bedrock interface at the location of theproduction wells is at over 20m. As is common with other basement areas within the humid tropics, the bedrock relief shows large variations from one location to another. Moreover, there are large variations in the overburden resistivity.

Resistivity soundings made at some of the conductivity highs suggest that such anomalies could be due to localised clay lenses, apart from deep weathering. Such clay lenses are likely to be poor aquifers on account of low permeability. This ambiguity indicates that some degree of caution need to be exercised while choosing borehole sites based on the results of EM surveys in similar climatic and hydrogeological environments. Another probable cause of high conductivities, namely high salinity of the groundwater, can be discountenanced since groundwaters from tropical basement areas are often very low in dissolved solids; the intense rainfall is very effective in diluting the soluble products of weathering, thus preventing high salinities (Todd 1959, Preez and Barber 1965).

The geophysical measurements have proved very successful in the identification of deeply weathered sites, with three of the four drilled holes completed as production wells.

ACKNOWLEDGEMENTS

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