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INTEGRATED VLF-ELECTROMAGNETIC AND ELECTRICAL RESISTIVITY SURVEY FOR GROUNDWATER IN A CRYSTALLINE BASEMENT COMPLEX TERRAIN OF SOUTHWEST NIGERIA.

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ABSTRACT

Very Low Frequency Electromagnetic (VLF-EM) and Electrical Resistivity (ER) methods were integrated in a feasibility study of a basement complex area for groundwater development. Linear features, suspected to be basement fractures, inferred from the VLF - EM anomaly curves, were confirmed by subsurface geoelectric images developed from interpretation results of the Vertical Electrical Soundings (VES).

The delineated basement fractures were penetrated by three test boreholes at various depth ranges of between 7.0 and 13.0 m beneath Borehole (BH) 3 & 4 and 9.0 - 42 m beneath BH5 for unconfined fractures and 36.0 - 38.0 m beneath BH3 & 4 and 128.0 - 188.0 m beneath BH5 for confined fractures. Borehole yields vary from 0.33 - 2.0 l/s, where two abortive (dry) boreholes (BH1 & 2) were previously drilled.

KEY WORDS: VLF - EM, Electrical Resistivity, Linear Features, Groundwater Development, Basement Complex Area.

INTRODUCTION

The Electromagnetic (EM) method has found useful applications in site investigation for groundwater development, most especially in basement complex area (de Rooy et. al., 1986; Palacky et. al., 1981; Hazell et. al., 1988; Amadi and Nurudeen, 1990; Olayinka, 1990 and Afolayan et. al., 2004). Its relevance is claimed to be in overburden thickness (depth to basement bedrock) estimation and basement fracture delineation.

In their assessment of the scope and limitations of the EM method, Olorunfemi et. al., (1995) observed that the EM method is more relevant in the delineation of near surface fractures than in the estimation of overburden thicknesses. The EM anomaly amplitudes were observed to be more influenced by the conductivity of the overburden (weathered layer) than the thickness. It was also observed that the EM method is not amenable to the mapping of confined fractures (Olorunfemi and Fasuyi, 1993) that are located within fresh and infinitely resistive basement rocks.

A drilling campaign for groundwater development in a basement complex area of Abeokuta township, Ogun State, Southwest, Nigeria (Figs, 1 & 2) failed after two abortive boreholes (BH1 & 2, Fig. 2) were drilled. The referenced site is underlain by granitic basement rock (Fig. 3). Although the basement rock is concealed within the premises of the site, outcrops of the basement rock are located at the immediate east of the site. It is therefore suspected that the overburden is relatively thin. The two dry holes confirmed the nearness of the basement rock by penetrating less than 5.0 m of the overburden into the fresh basement rock.

The relatively thin overburden (weathered layer) has limited hydrogeological significance as manifested by the dry boreholes. For a borehole to be productive within such premises, it will have to penetrate water bearing basement fractures.

The electromagnetic and resistivity methods are both responsive to water bearing basement fracture columns due to the relatively high bulk electrical conductivities. Both methods were therefore found relevant and were hence integrated in the investigation of the referenced site. The EM method was adopted as a fast reconnaissance tool to map possible linear features such as faults and fracture zones while the electrical resistivity method was used to investigate prominent EM anomalies and provide a geoelectric image of the subsurface sequence.

THE GEOPHYSICAL INVESTIGATION

The geophysical investigation involved the Very Low Frequency (VLF) electromagnetic and Electrical Resistivity methods. The VLF - EM measurements were made at 5.0 m interval along twenty two (22) approximately east - west traverses (Fig. 2). The VLF traverses range in length from 60 - 150 m. The GEONICS EM16 VLF - EM Unit was used for the data collection. The equipment measured the real (in phase) and quadrature (out of phase) components of the vertical to horizontal magnetic field ratio.

Although both real and quadrature components of the VLF - EM anomalies were recorded, the real component data being usually more diagnostic of linear features were processed for qualitative interpretation.

A filter operator:

$$Q_{1.5} = (Q_{i+3} + Q_{i+2}) - (Q_i + Q_{i+1})$$

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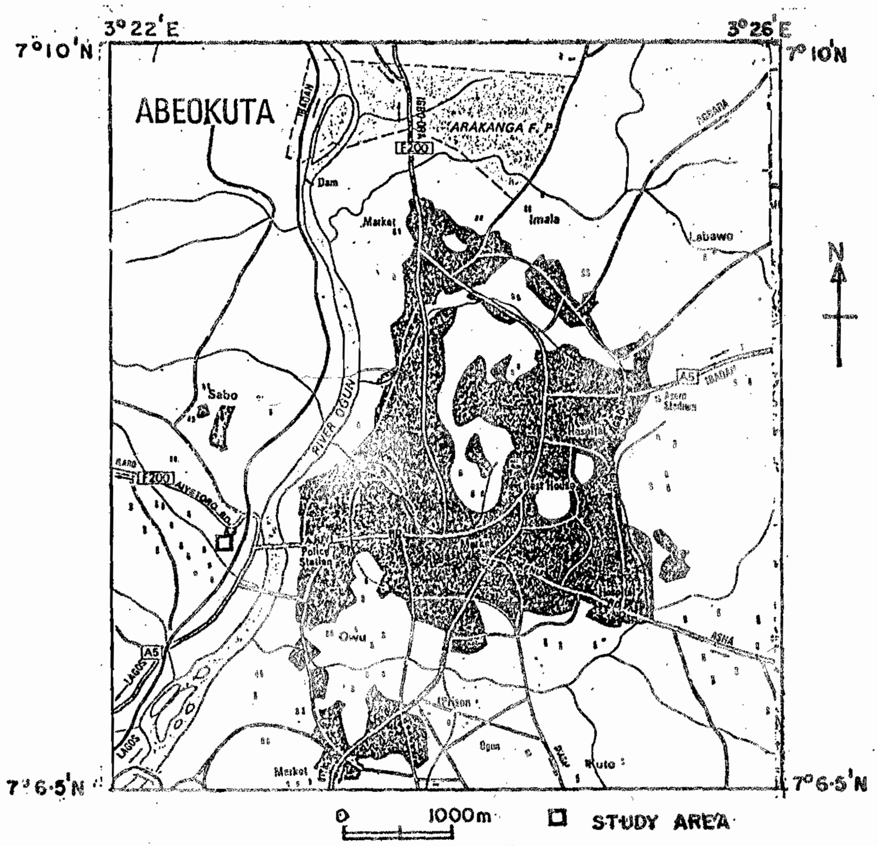

FIG. 1: MAP OF ABEOKUTA CITY SHOWING THE STUDY AREA (EXTRACTED FROM ROAD MAP OF NIGERIA, PRINTED BY ACADEMY PRESS LTD, LAGOS).

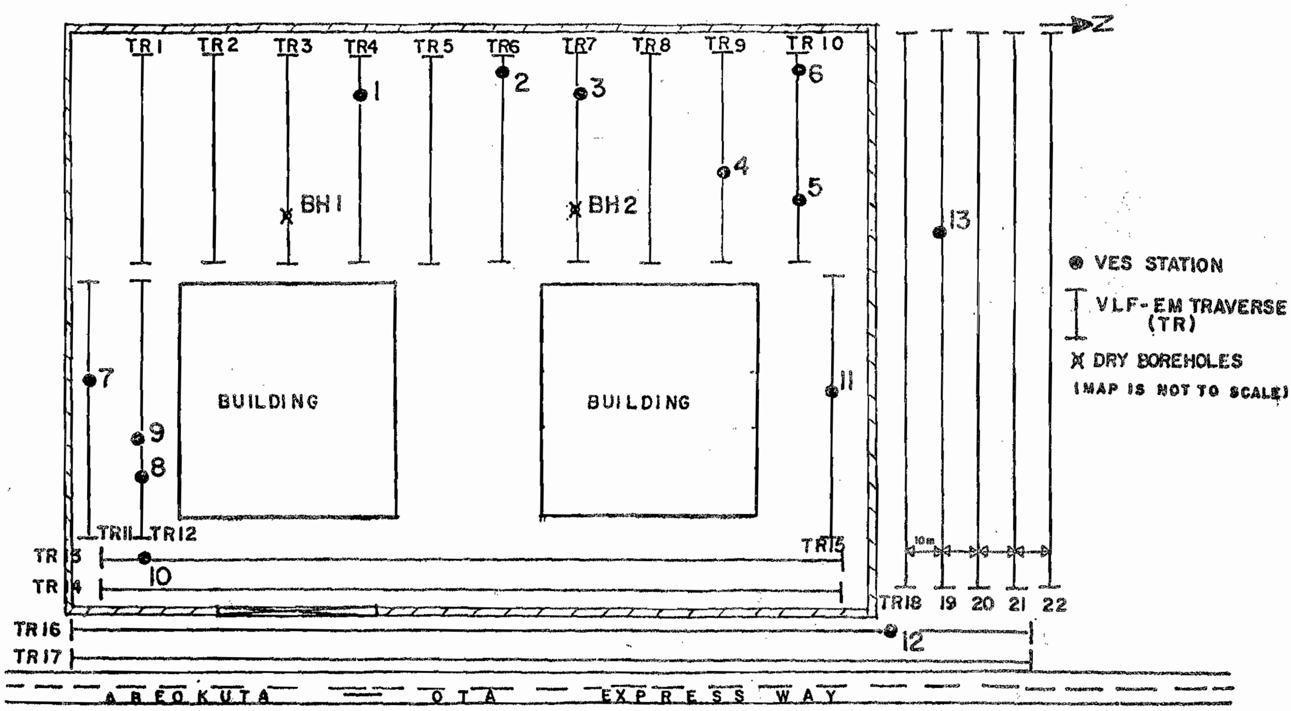

FIG. 2: SKETCH MAP OF THE SURVEY AREA SHOWING VERTICAL ELECTRICAL SOUNDING (VES) STATIONS AND VLF-EM TRAVERSES.

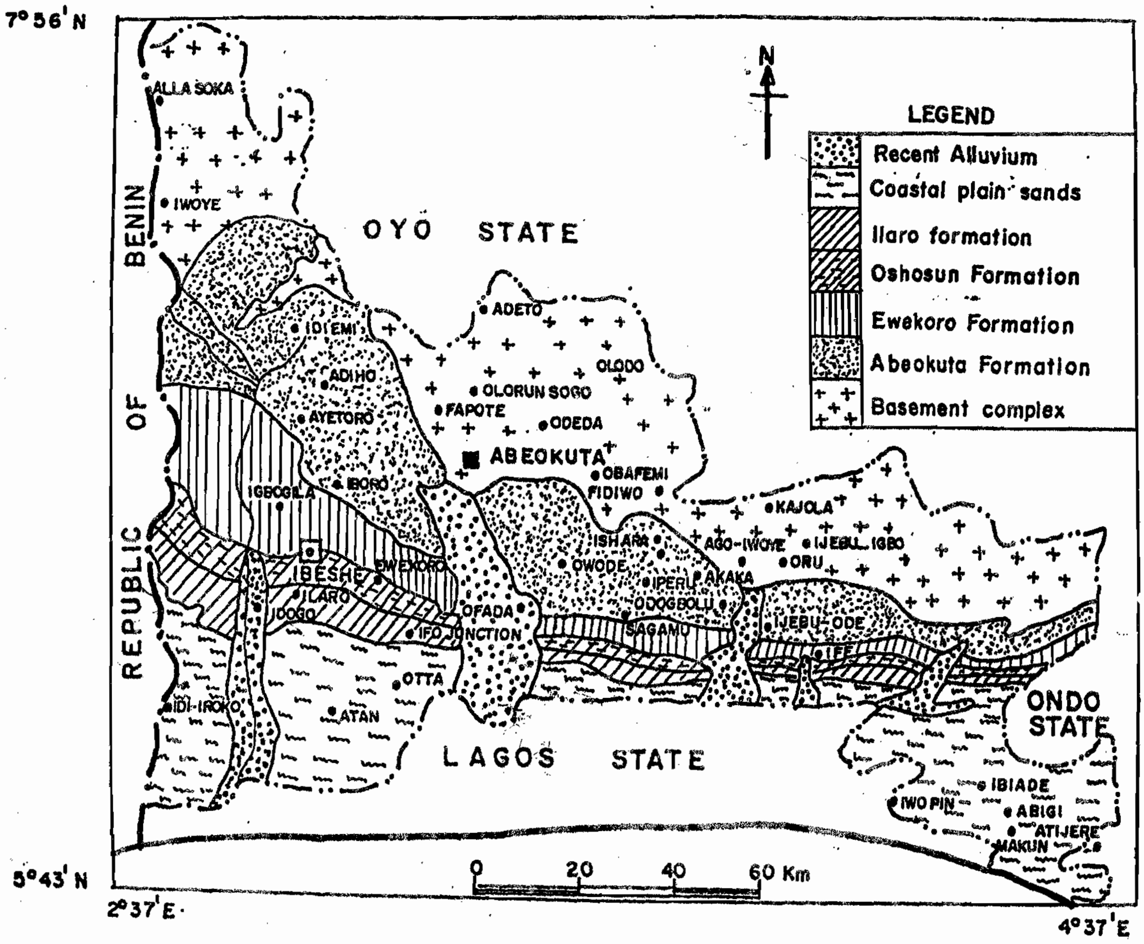

FIG.3 : GEOLOGICAL MAP OF OGUN STATE

STUDY AREA

(for n data and i = 1 to n-3 where Q are EM data and the subscripts are the station positions) was applied to the real component VLF - EM data to transform the data set to filtered real VLF - EM data (Karous and Hjelt, 1983). The filtered real data transform every genuine crossover or inflection points of the real anomaly to positive peaks while reverse crossovers become negative peaks.

A double plot of the real and filtered real anomaly curves enabled qualitative identification of the top of linear features as points of coincident of crossovers and positive peaks of the real and filtered real anomaly curves.

The electrical resistivity method involved the vertical electrical soundings (VES) with Schlumberger array. The soundings (thirteen in all) were carried out at locations of prominent VLF anomalies, presumably typical of basement fractures. The electrode spacing was varied from 3.0 - 100 m with maximum spread length of 200 m.

The PASI 16GL Digital Resistivity Meter was used for the data collection.

The VES curves (plots of apparent resistivity against spacing on log-log graph papers) were interpreted quantitatively using the partial curve matching and computer iteration methods. The W-Geosoft/WinSev 5.1 software was used for the 1-D computer modelling.

RESULTS AND DISCUSSION

Figures 4a-v present the VLF - EM anomaly curves (real and filtered real) along traverses TR1 - TR22. Thirteen major linear features (suspected geological interfaces f_1 - f_{13}) with positive peak filtered real amplitudes > 30 % were delineated using characteristic feature of coincident inflections on real component anomaly curves with positive peaks on filtered real anomaly curves. These features are suspected to be basement fractures and are prominent along traverses TR4, TR6, TR7, TR9, TR10, TR11, TR12, TR13, TR15, TR16 and TR18 (see Fig. 2). Both dry boreholes BH1 and BH2 were located on negative peaks (Fig. 2) typical of unfissured basement. The freshness of the basement rock at both borehole sites corroborated the above inference.

Vertical Electrical Soundings (13 Nos.) were carried out at the locations of the identified suspected linear features f_1 - f_{13}. Some of the VES curves (Fig. 5) show characteristic features of both

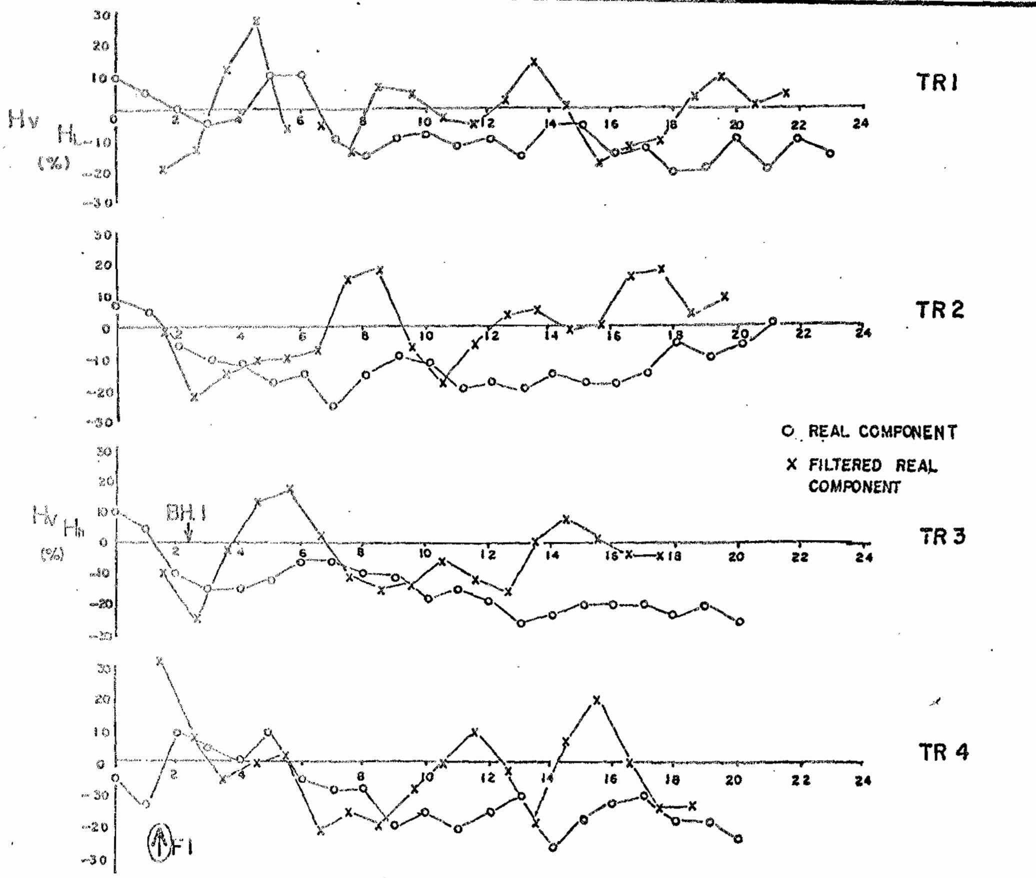

FIG.4 a-d : VLF ANOMALY CURVES (REAL AND FILTERED REAL COMPONENTS) ALONG TRAVERSES (TR) 1-4.

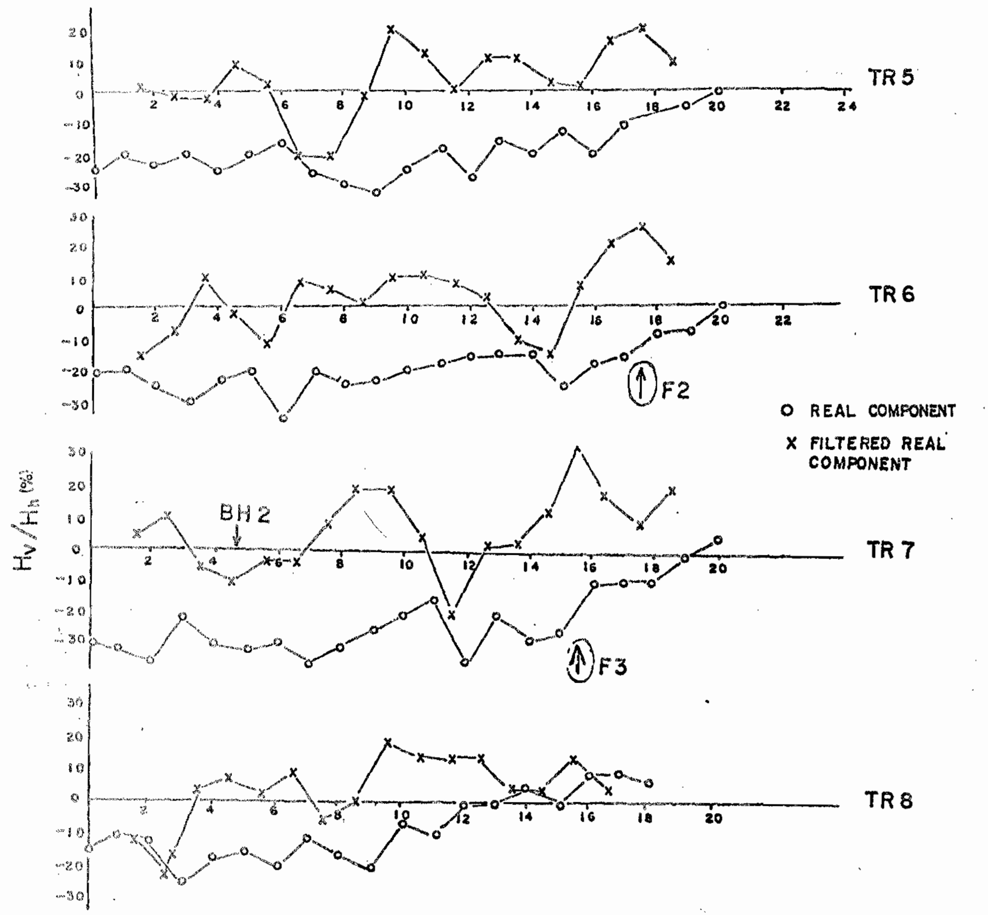

FIG4 e-h : VLF ANOMALY CURVES (REAL AND FILTERED REAL COMPONENTS) ALONG TRAVERSES (TR)5-8

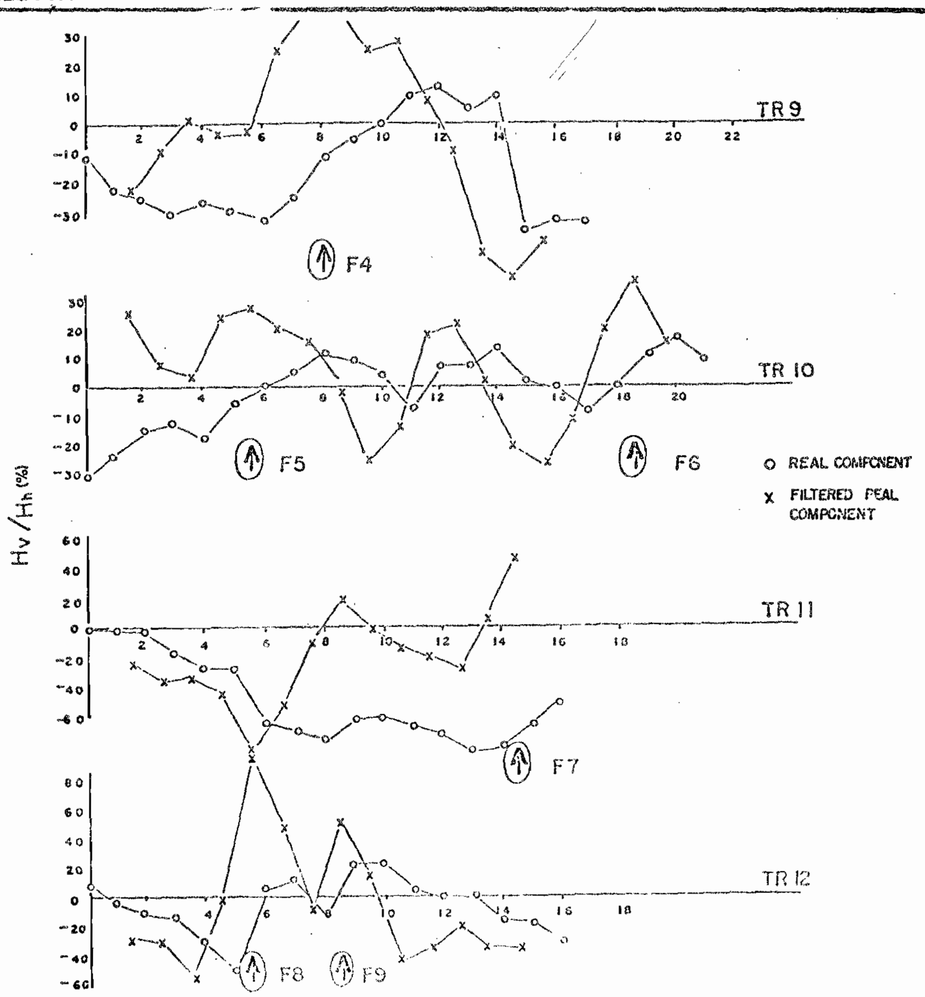

FIG.4 i-l: VLF ANOMALY CURVES (REAL AND FILTERED REAL COMPONENTS) ALONG TRAVERSES (TR) 9-12.

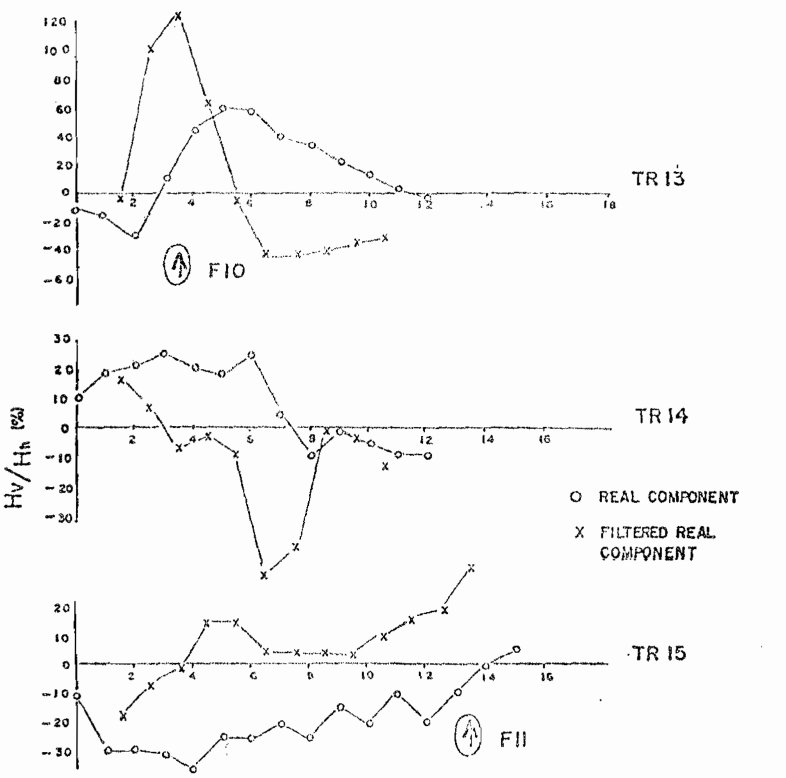

FIG.4 m-o: VLF ANOMALY CURVES (REAL AND FILTERED REAL COMPONENTS) ALONG TRAVERSES (TR) 13-15.

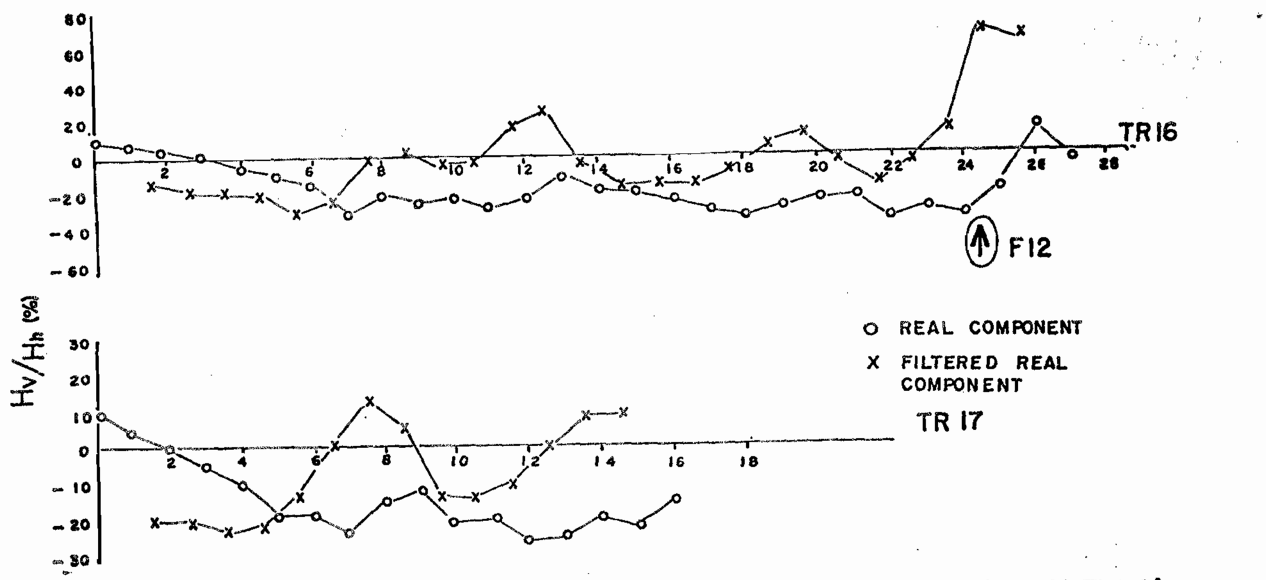

FIG.4 p&q: VLF ANOMALY CURVES (REAL AND FILTERED REAL COMPONENTS) ALONG TRAVERSES (TR) 16-17.

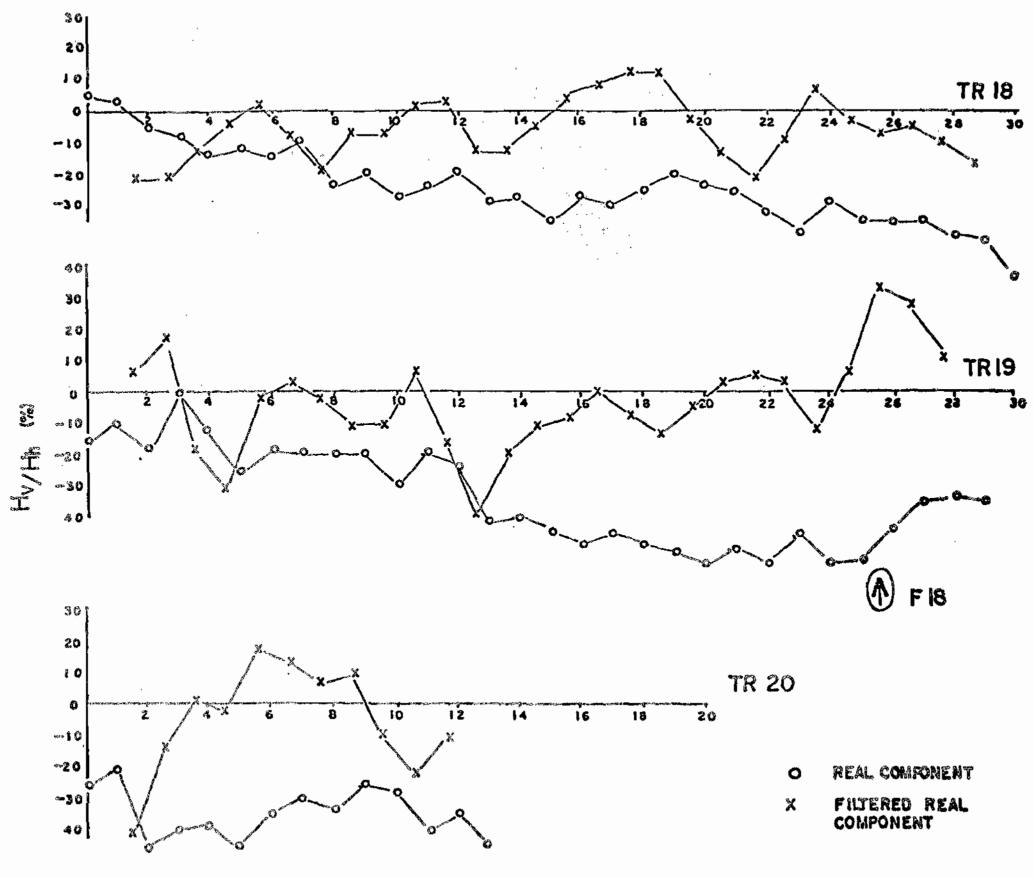

FIG.4 r—t: VLF ANOMALY CURVES (REAL AND FILTERED REAL COMPONENTS)ALONG TRAVERSES (TR) 18-20.

unconfined fractures (as A and HA type curve in VES 4, 2/8) and confined fractures (as KH and HKH type curve in VES 6 and 5 respectively). Confine fractures are characterized by inflections (arrowed in Fig. 5) along the rising (basement) segments of the VES curves (Olorunfemi and Fasuyi, 1993; Olorunfemi et. al. 1999 and Ademilua and Olorunfemi, 2000). Where fractured columns are deep and thin or density of fracture is low, such inflection may not be prominent on the VES curve. The interpretation results of the VES curves are presented as geoelectric sections in Figures 6a-c.

The geoelectric sections identified four subsurface geologic

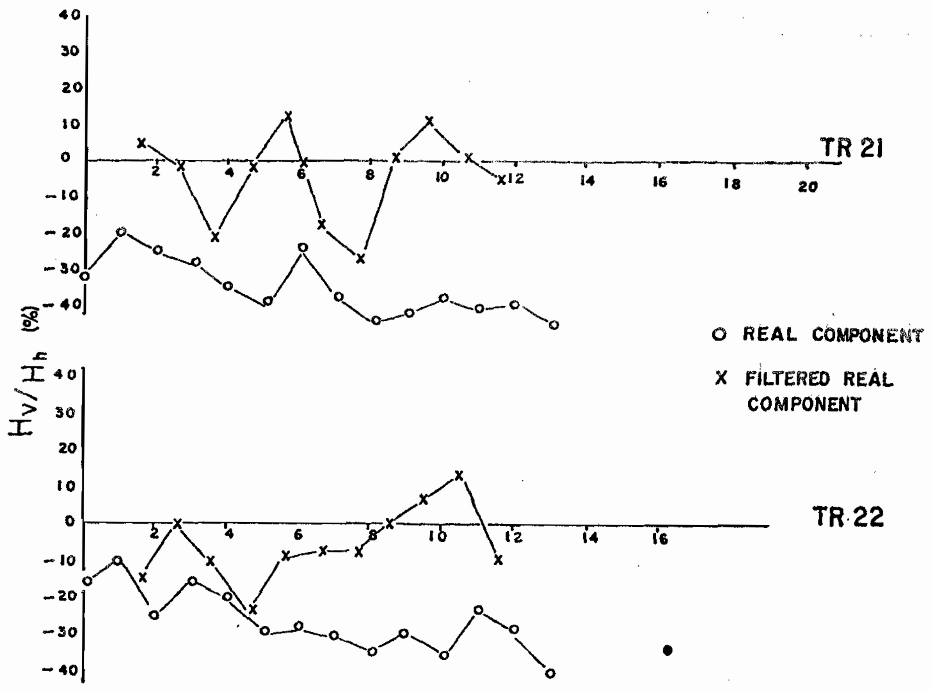

FIG.4. u-v : VLF ANOMALY CURVES (REAL AND FILTERED REAL COMPONENTS) ALONG TRAVERSES (TR) 21-22.

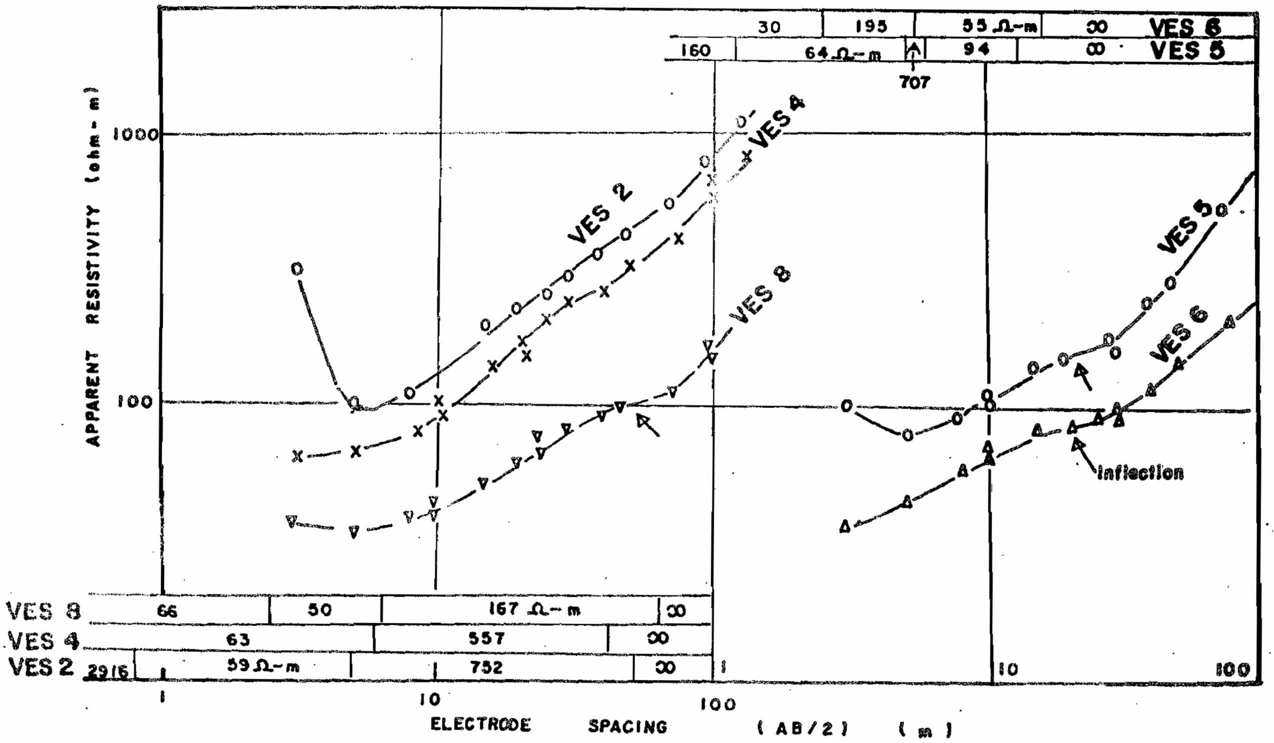

FIG. 5 : TYPICAL VES CURVES AND INTERPRETATION MODELS.

sequence which include the topsoil, clayey weathered layer, partly weathered/fractured/fresh basement and fresh basement bedrock. The sections depict an area with relatively thin (2.5 - 8.8 m) overburden but fairly thick partly weathered/fractured basement column. The latter constitutes the main aquifer unit.

Three of the VES stations (2, 4 and 8) were test drilled to depths varying from 69 m to 244 m (Fig. 7). The three boreholes penetrated basement fractures as interpreted from the VLF - EM curves and corroborated by the geoelectric sections.

Unconfined fractures, located directly beneath the weathered layer, were encountered at depth columns varying from 7.0 - 13.0 m beneath Borehole (BH 3 & 4) and 9.0 - 42m beneath BH5 while confined fractures, concealed within fresh basement rock, were encountered between 36.0 m and 38.0 m beneath BH3 & 4 and 128.0 - 188.0 m beneath BH5 (see Fig. 7). The fractures delineated at deep depth (128 - 188 m) beneath BH5 may be dry fractures resulting in loss of groundwater and consequently low groundwater yield in a borehole with good prospect for significant yield at shallow depth of less than 70 m. The groundwater yield obtained from the three boreholes ranges from 0.33 l/s to 2.0 l/s (see Fig. 7).

CONCLUSION

Geological features suspected to be basement fractures identified from VLF - EM anomaly curves were confirmed by geoelectric subsurface images developed from interpretation results of vertical electrical soundings.

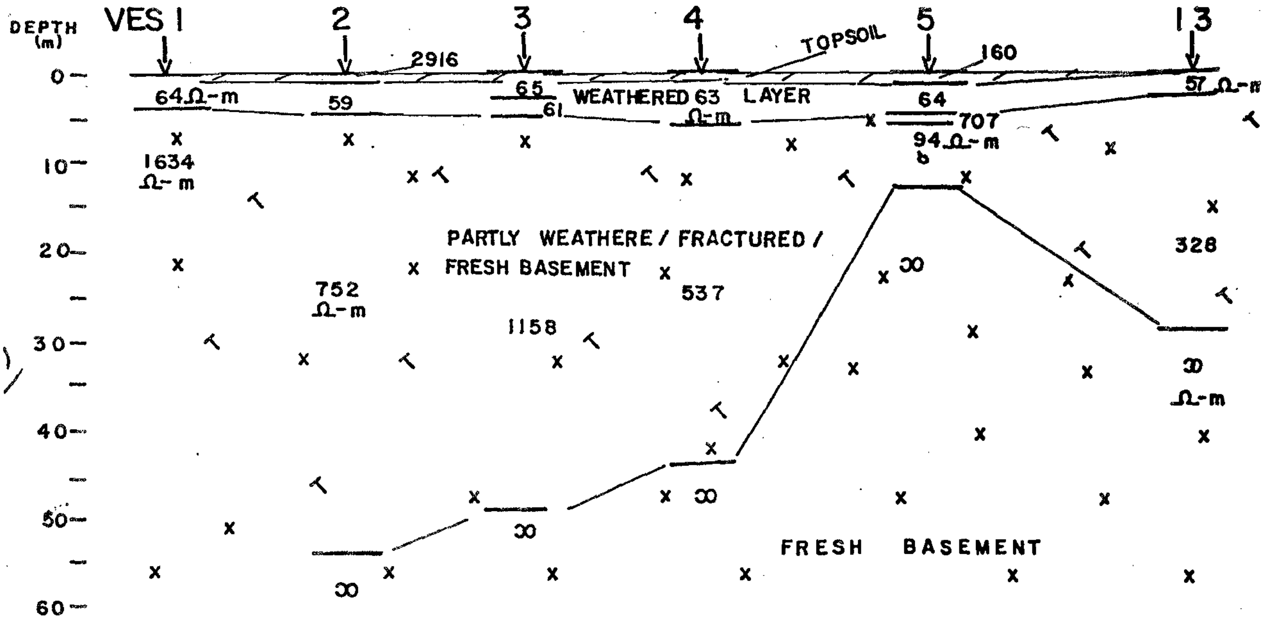

FIG.6a: GEOELECTRIC SECTION RELATING VES 1, 2, 3, 4, 5 AND 13

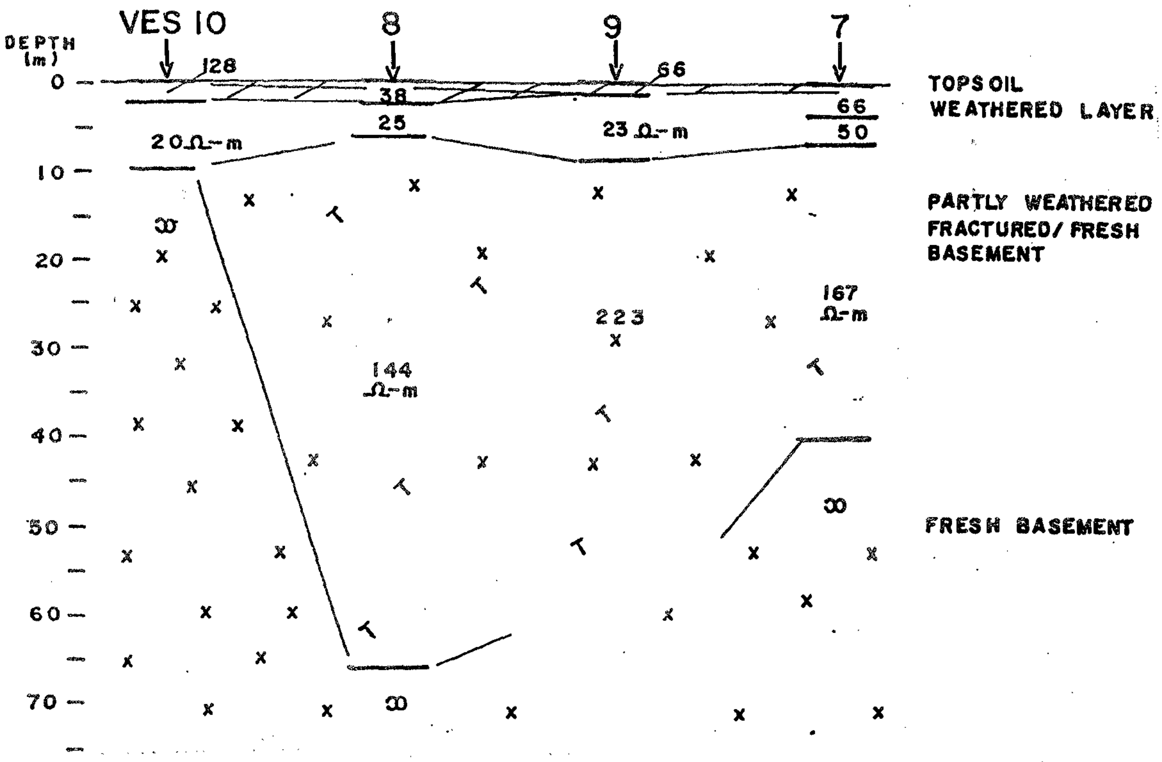

FIG 6b: GEOELECTRIC SECTIONS RELATING VES 10,8,9 AND 7.

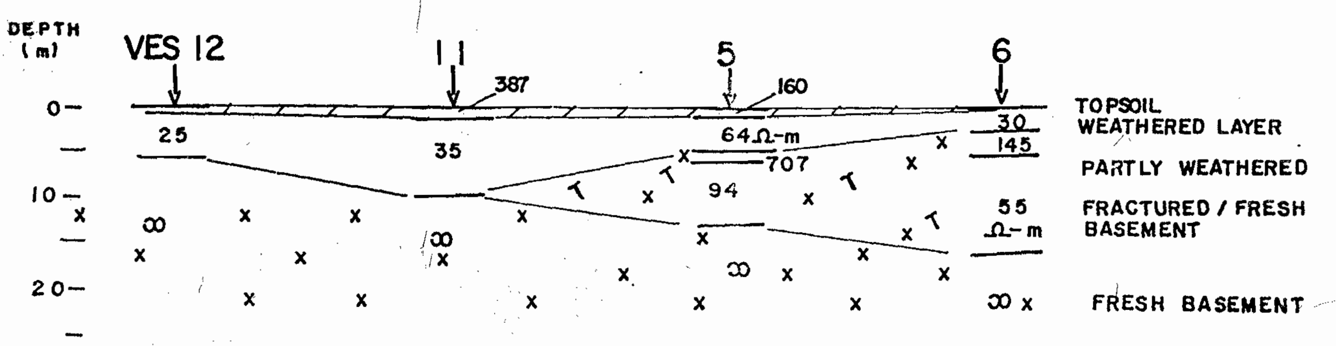

FIG.6c: GEOELECTRIC SECTION RELATING VES. 12, 11, 5 AND 6.

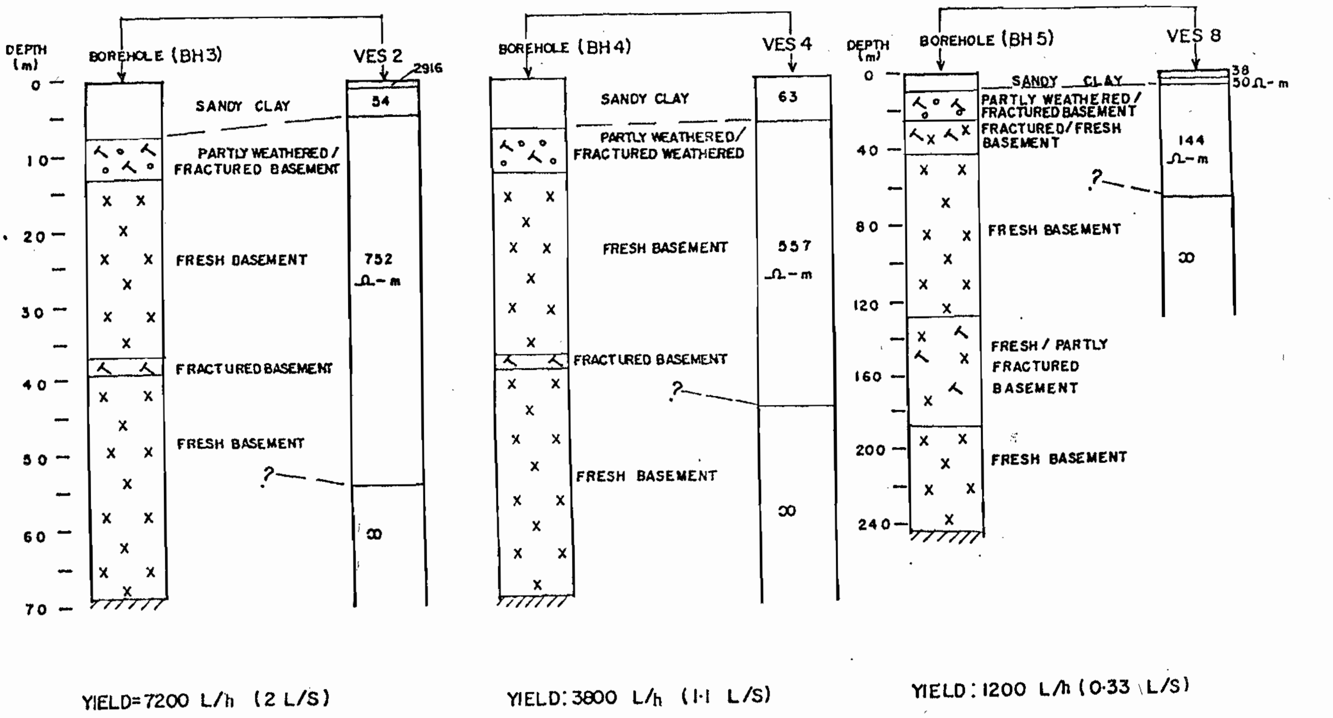

FIG. 7 : CORRELATION OF BOREHOLE LOGS WITH VERTICAL ELECTRICAL SOUNDING (VES) INTERPRETATION RESULTS.

The integration of the VLF - EM and electrical resistivity sounding results enabled identification of locations for productive boreholes (with groundwater yield of up to 2.0 l/s) within an area where dry boreholes were previously drilled.

This case study also highlights the discrete nature of basement aquifers.

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