COMBINED VLF-EM AND GEOELECTRIC SOUNDING FOR GROUNDWATER DEVELOPMENT IN A TYPICAL BASEMENT COMPLEX TERRIAN OF SOUTH WESTERN, NIGERIA

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Abstract: An assessment of three failed boreholes that were earlier drilled at Ibusogboro Area of Ibadan was carried out using integrated Very Low Frequency-Electromagnetic (VLF-EM) and Electrical Resistivity (ER) methods. The aim was to investigate the causes of the borehole failure and to identify suitable site for groundwater development based on geoelectrical properties of the subsurface layers. Sixteen (16) VLF-EM profiles were used to delineate linear geologic structures within the study location. Seven (7) Vertical Electrical Soundings (VES) stations were occupied at the identified lineament zones. Four geoelectric units were delineated. These include the topsoil, weathered/partially weathered layer, fractured basement and the fresh bedrock with resistivity values which ranged between 91 and 698 Ωm, 20 and 213 Ωm, 55 and 225 Ωm, and 149 and 1399 Ωm, respectively. The result of VLF-EM revealed that the failed boreholes were located on unfissured fresh basement rock. The VES carried out at the VLF-EM delineated lineament zones revealed fractured basement at four locations. Test boreholes (BH) 4 and 5 were drilled at VES 2 and 6 to penetrate the fractured basement and yields of 2300 and 4400l litres/h were acquired through pumping test, respectively.
Keywords: Very low frequency-electromagnetic, electrical resistivity, pumping test, geoelectric properties

Introduction

Surface geophysical investigation involving (VLF-EM) and (ER) methods have proved very useful in the identification of weathered basement and fracture that is favourable for groundwater accumulation. The VLF-EM method is responsive to water bearing basement fracture columns due to the relatively high bulk electrical conductivities. This is the reason why the application of the VLF-EM method has been found useful in site investigation for groundwater development, especially, in the Basement Complex area (Hazell *et al*., 1988; Olayinka, 1990; Olorunfemi *et al*., 2004; Adiat *et al*., 2009; Ariyo*et al*., 2009; Bayowa *et al*., 2014; Akinrinade and Olabode, 2015) with its relevance in overburden thickness estimation and basement fracture delineation. The electromagnetic method is however more relevant in the delineation of near surface fractures than in the estimation of overburden thickness as observed by Olorunfemi *et al*. (1995).

The VES technique has been found effective in aquifer identification (Ako, 1989; Mbonu *et al*., 1991). The electrical resistivity survey is also widely employed in the delineation of basement regolith and location of fracture or fissured media and associated zones of deep weathering in crystalline terrains (Hazell *et al*., 1988; Beeson and Jones, 1988; Olayinka*et al*., 2004; Olorunfemi *et al*., 2004). The aim of this study was to explore the combination of VLF-EM and ER methods to locate feasible points for productive boreholes in a Farm settlement at Ibusogboro and identify the cause(s) of the three abortive boreholes that had earlier been drilled in the farm. The VLF-EM method was adopted as a reconnaissance tool to map possible linear features such as faults and fracture zones while the electrical resistivity (ER) method was used to investigate prominent VLF-EM anomalies and provide a geoelectric image of the subsurface sequence.

Site location and geology of the study area

The study site is a Farm settlement (Fig. 1) situated at Ibusogboro along Ibadan-Ago Iwoye Road, Ibadan, Oyo State. It is one of the largest Farm settlements in the South Western, Nigeria. The study area is relatively flat. The site is underlain by the Precambrian Basement composed of schist that is concealed within the subsurface.

Materials and Method

Sixteen (16) profiles were established within the study area. VLF-EM measurements were made at 10 m interval along these profiles **(**Fig. 1**)**. The VLF-EM profiles ranged in length from 90 to 290 m. SCINTREX VLF-EM Unit was used for the data collection. The equipment measured the real (in phase) and quadrature (out phase) components of the vertical to horizontal magnetic field ratio. The real component data were processed for interpretation. The KHFfilt software (KHFfilt Version 1.0) was used for 2D inversion of the real component data.

The electrical resistivity method involving the Vertical Electrical Soundings (VES) was carried out using the Schlumberger electrode configuration. The PASI 16 GL Digital Resistivity Meter Model was used for the data collection. Seven (7) VES were occupied at locations of prominent VLF anomalies, presumably typical of basement fractures (Olorunfemi *et al*., 2004). The electrode spacing was varied from 1 to 120 m with maximum spread length of 240 m. The VES curves were interpreted quantitatively using partial curve matching and computer assisted forward modelling using Winglink resist Software.

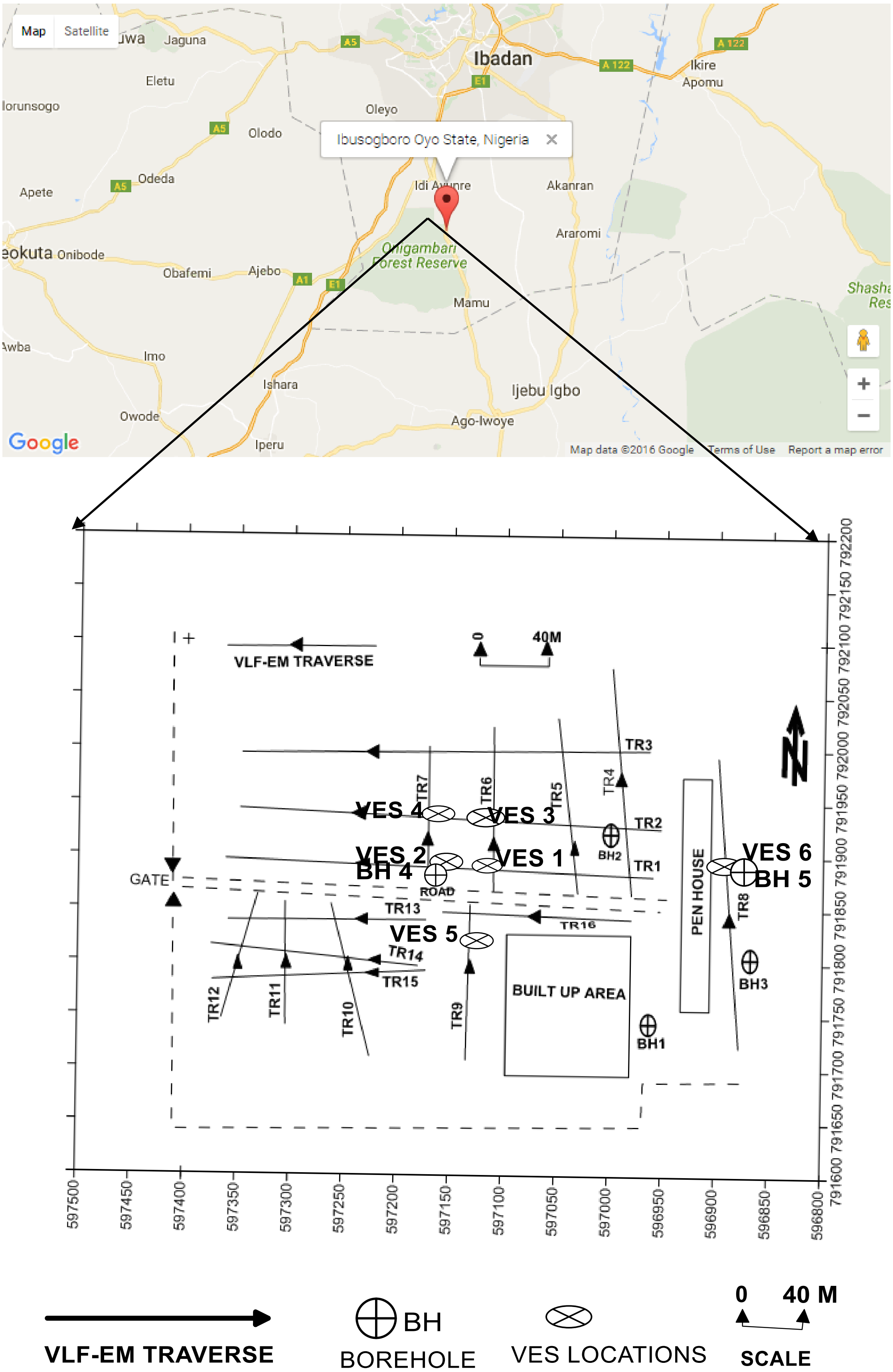


Fig. 1: The google map of Ibosogboro showing the study site

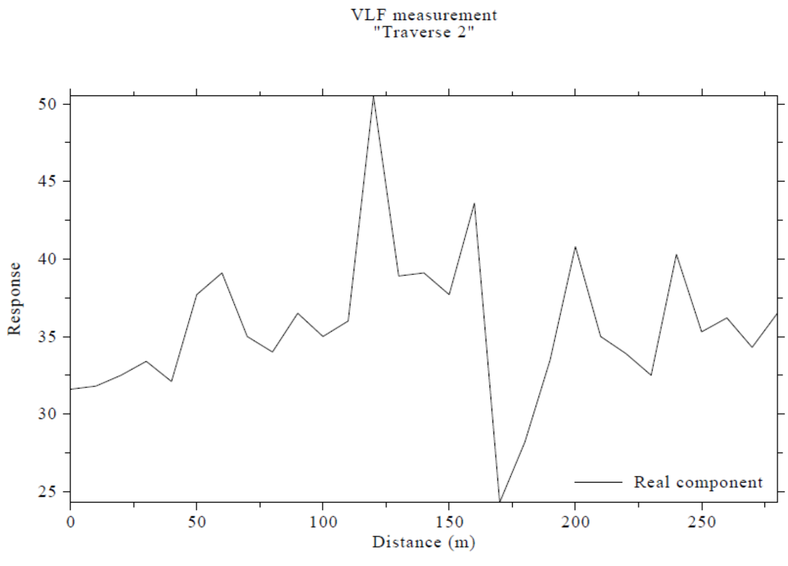
Results and Discussion

Table 1 shows the Traverse (TR) number, the VES location and the description of the five localities that are suspected from VLF-EM results to be underlain by thick weathered zone and fractured basement rock. Fig. 2-5 show real and filtered real component of VLF-EM anomaly profiles and 2-D subsurface images obtained along four (4) traverses out of the sixteen (16) VLF-EM traverses. The filtered real anomalies are generally of low amplitude (<10%) and in most cases significantly above the threshold of 20%, which is presumed to be typical of thick weathered zone and fractured basement in the area. Six major linear features suspected to be geological structures (X_1-X_6, Figs. 2 - 5) with positive peaks filtered real amplitude >10% were delineated using characteristic feature of coincidence of inflections on real component anomaly curves (Ariyo *et al.*, 2009). The zones of positive peak filtered real anomaly that corresponded to high conductivity are identified on traverses TR2, TR3 and TR8 and have depths of penetration varying between 10 and 40 m. It can be observed that the failed boreholes BH2 and BH3 were located on the trough of the filtered real anomaly curve which is indicative of resistive and unfissured fresh Basement rock (Figs. 2, 4 and 5). BH2 and BH3 were located at 40 m on traverse 4 and traverse 8, respectively with negative peaks (trough) filtered real while BH1 was not located on any traverse.

Table 1: Traverse number, VES numbers and description VES position

S/N	Traverse (TR) No.	VES No.	Description of VES position from a reference station zero
1	TR 2	VES 1	80 m from station 0
2	TR 2	VES 2	100 m from station 0
3	TR 3	VES 3	80 m from station 0
4	TR 3	VES 4	120 m from station 0
5	TR 8	VES 6	140 m from station 0

Figures 6a and 7a show typical VES curves obtained from the survey area. Some VES positions were correlated with borehole positions as shown in Figs. 6b and 7b. There is significant correlation between the VES sections and the borehole lithological logs. The interpreted VES results revealed four geoelctric layers comprising the topsoil, weathered/partially weathered basement, fractured basement and fresh basement as shown in Fig. 8. The topsoil is very thin with thicknesses ranging from 0.7 to 2.8 m and resistivity values of between 91 and 698 Ωm. The layer is made up of lateritic clay formation. The second layer is the weathered/partially weathered basement. It is relatively thick with thicknesses ranging from 2.7 to 18 m and resistivity values of between 20 and 213 Ωm. This layer may be saturated with water but may not be able to yield substantial water because the low resistivity is an indicative of its high clay content. The third layer is the resistive fresh Basement rock with resistivity values ranging between 149 and 1399 Ωm. The fourth layer is the fractured basement with resistivity values ranging between 55 and 225 Ωm. The fractured basement constitutes the aquifer and it was observed at VES (1, 2, 4 and 6) locations out of the seven locations that were sounded. VES 2 and VES 6 were subsequently drilled to a maximum depth of 45.0 m each for groundwater development. The observed yield results were 2300 and 4400 litres/h at BH 4 and 5, respectively after pump testing analysis.



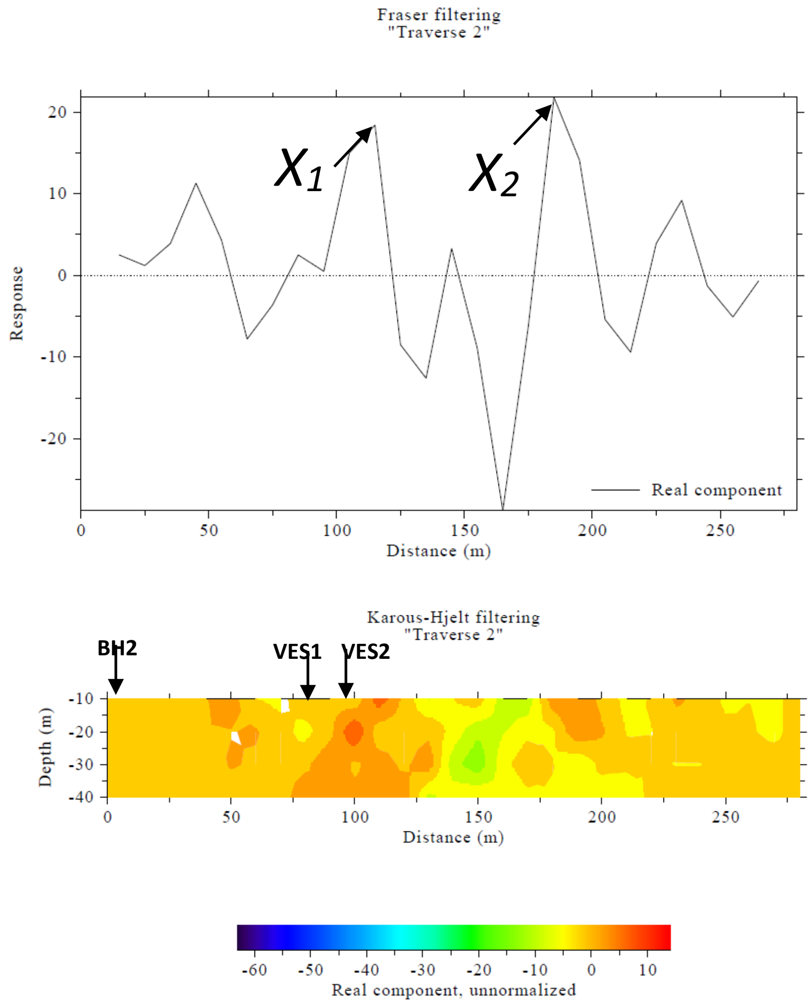
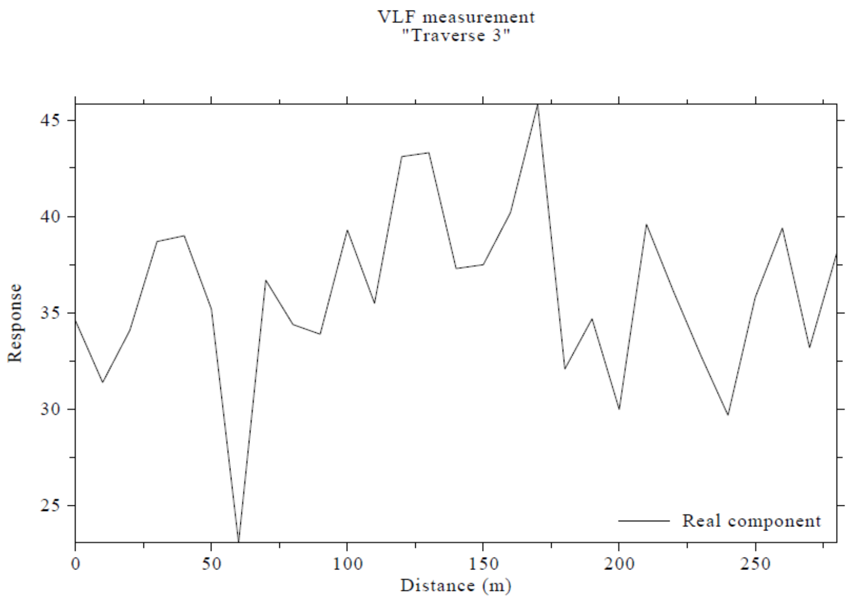


Fig. 2: (a) VLF-EM real component and **(b)** Filtered real component anomaly profiles and **(c)** 2-D subsurface image along traverse 2



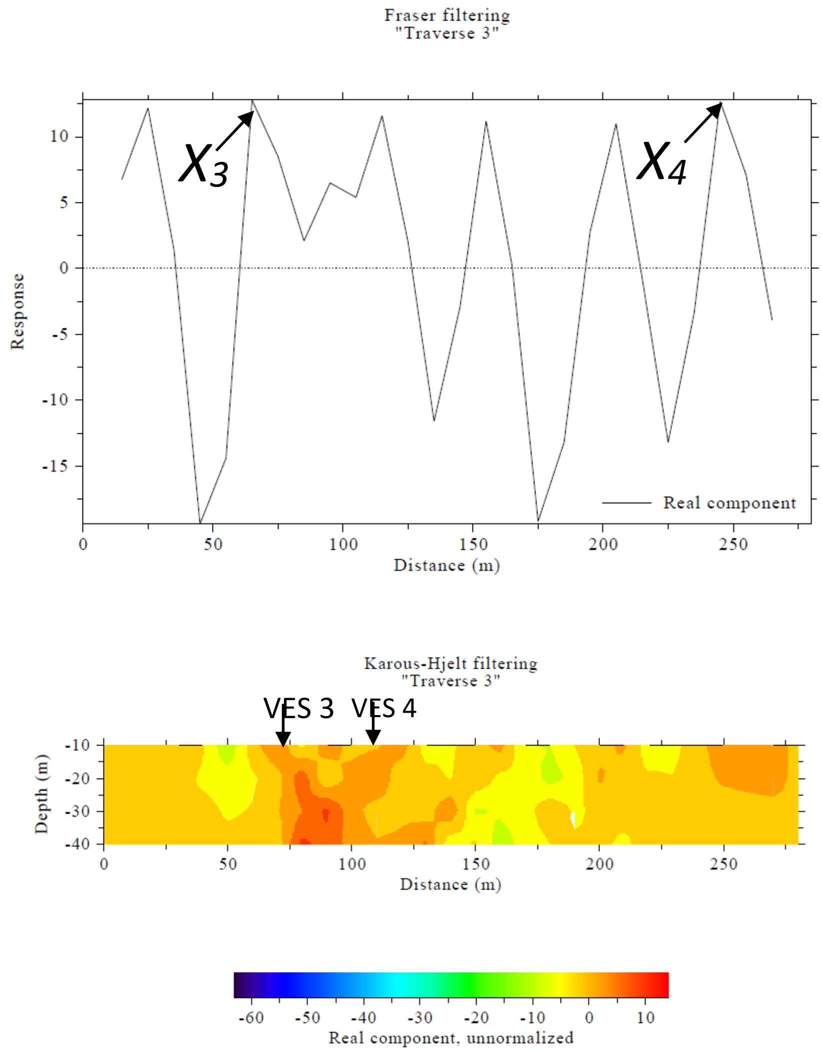


Fig. 3: (a) VLF-EM real component and **(b)** Filtered real component anomaly profiles and **(c)** 2-D subsurface image along traverse 3

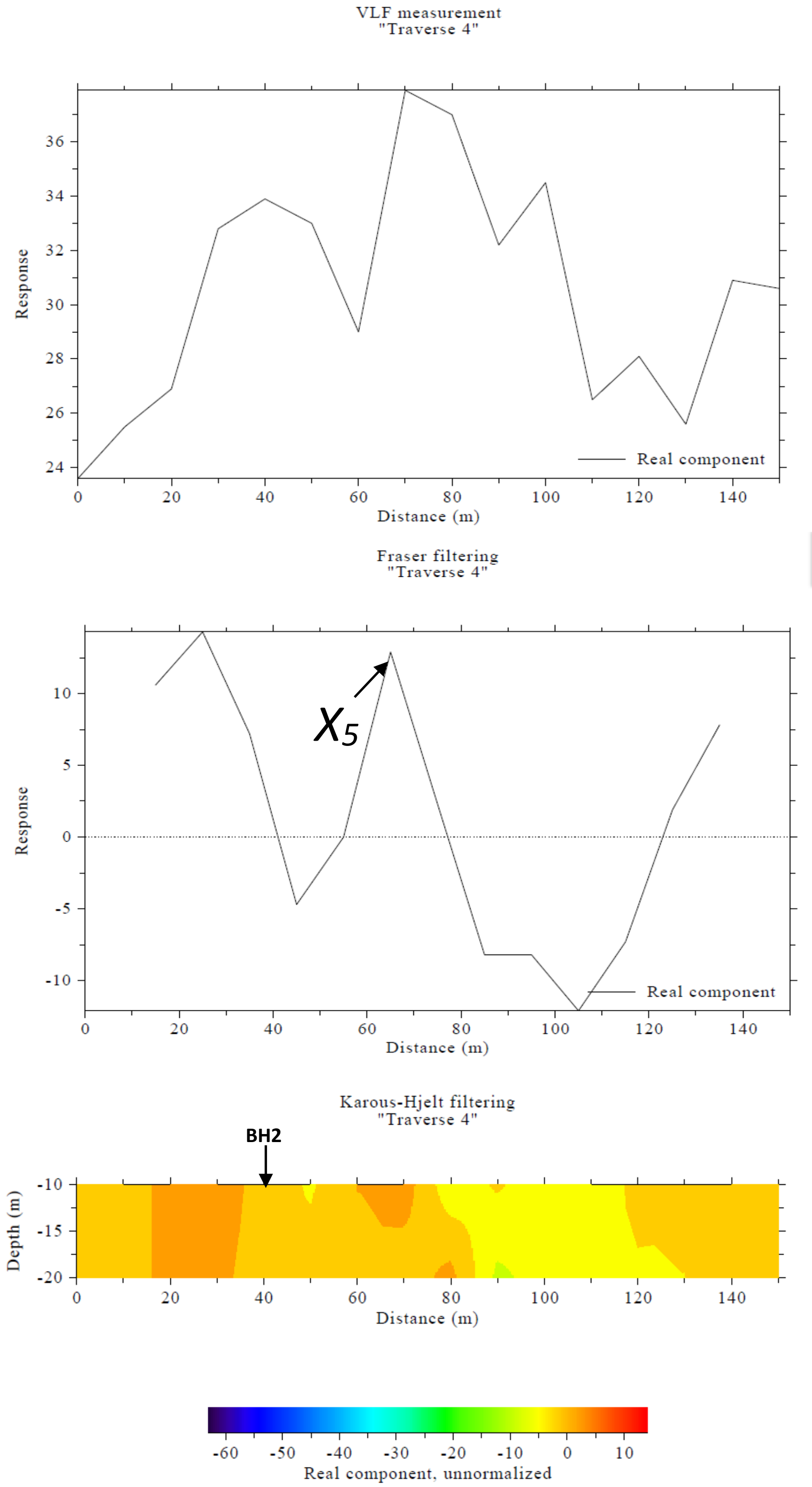


Fig. 4: (a) VLF-EM real component and **(b)** Filtered real component anomaly profiles and **(c)** 2-D subsurface image along traverse 4

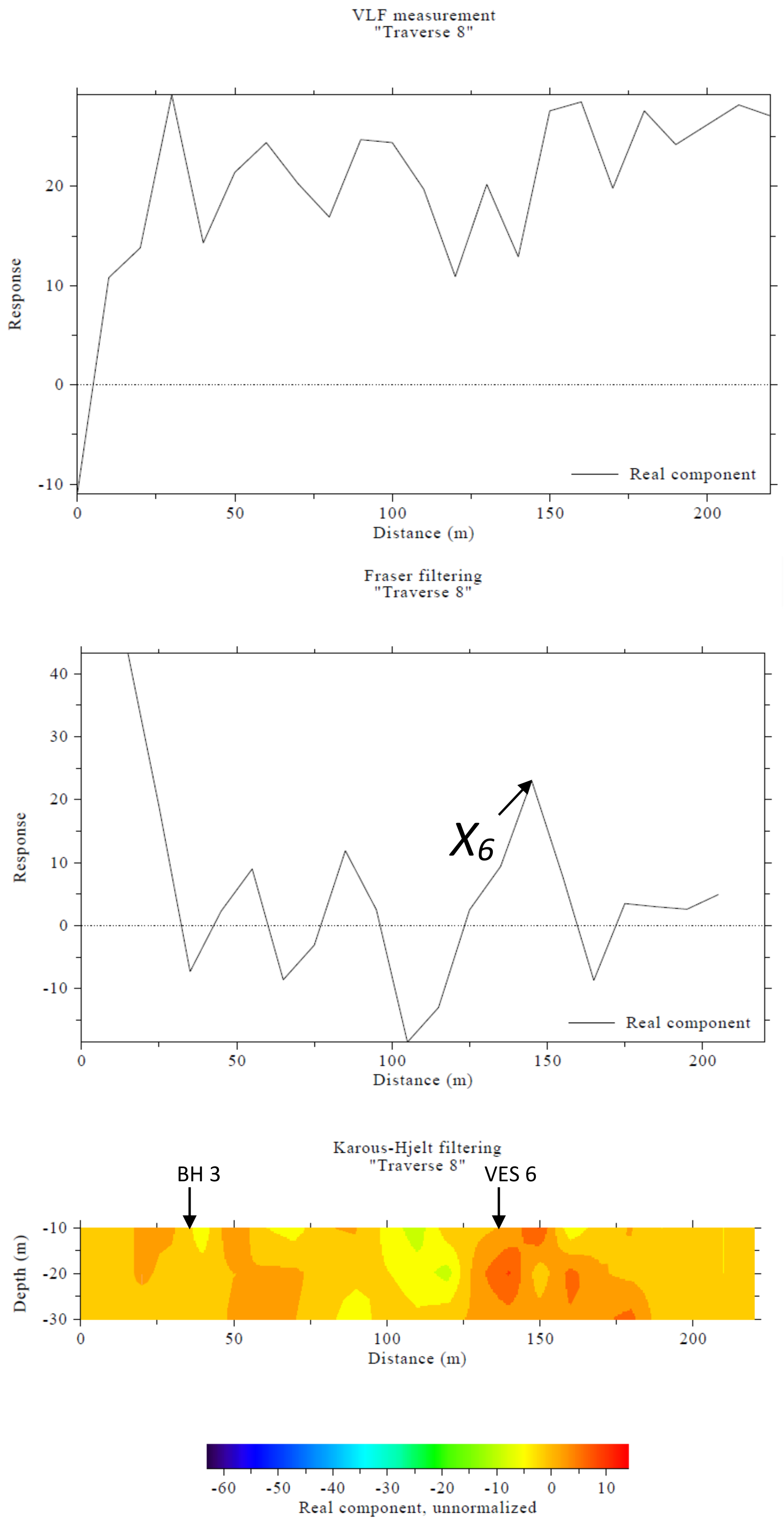


Fig. 5: (a) VLF-EM real component and **(b)** Filtered real component anomaly profiles and **(c)** 2-D subsurface image along traverse 8

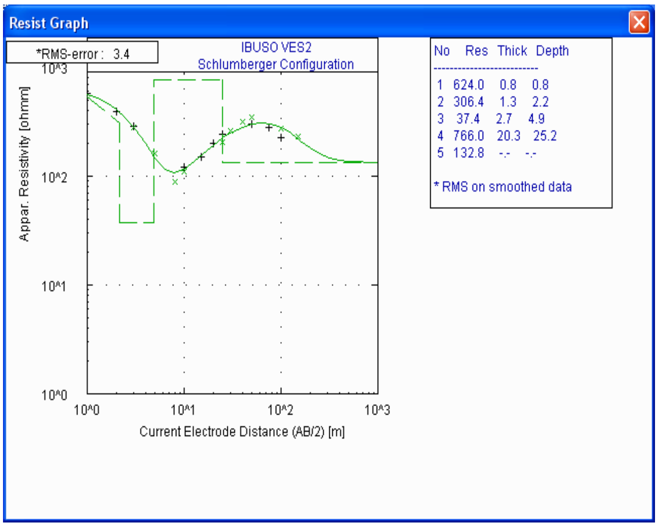


Fig. 6a: Typical VES curve showing VES 2 geoelectric parameters.

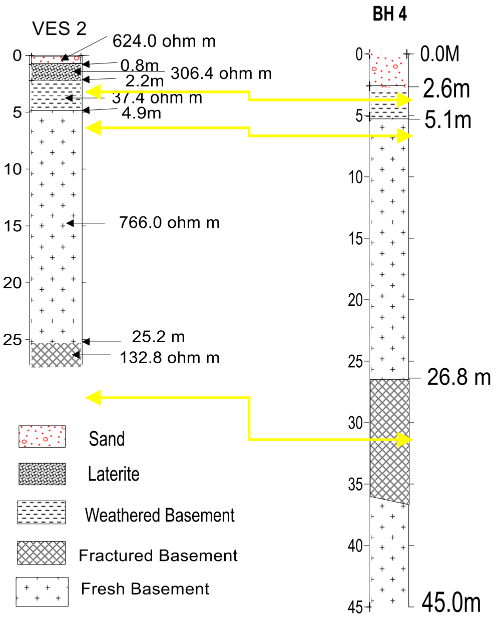


Fig. 6b: Graphical correlation of geoelectrical parameters and Borehole between VES 2 and BH4.

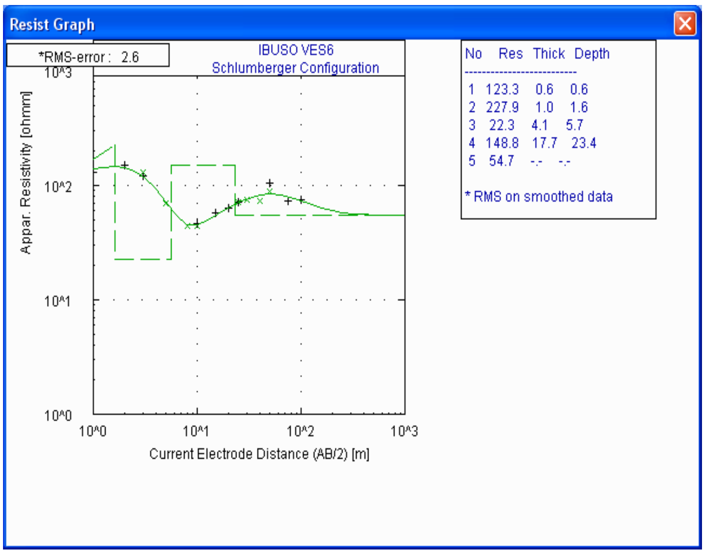


Fig. 7a: Typical VES curve showing VES 6 geoelectric parameters

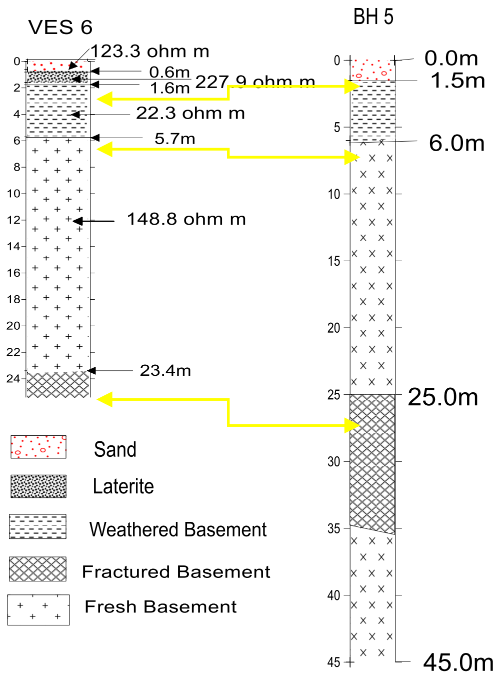


Fig. 7b: Graphical correlation of geoelectrical parameters and borehole between VES 6 and BH5

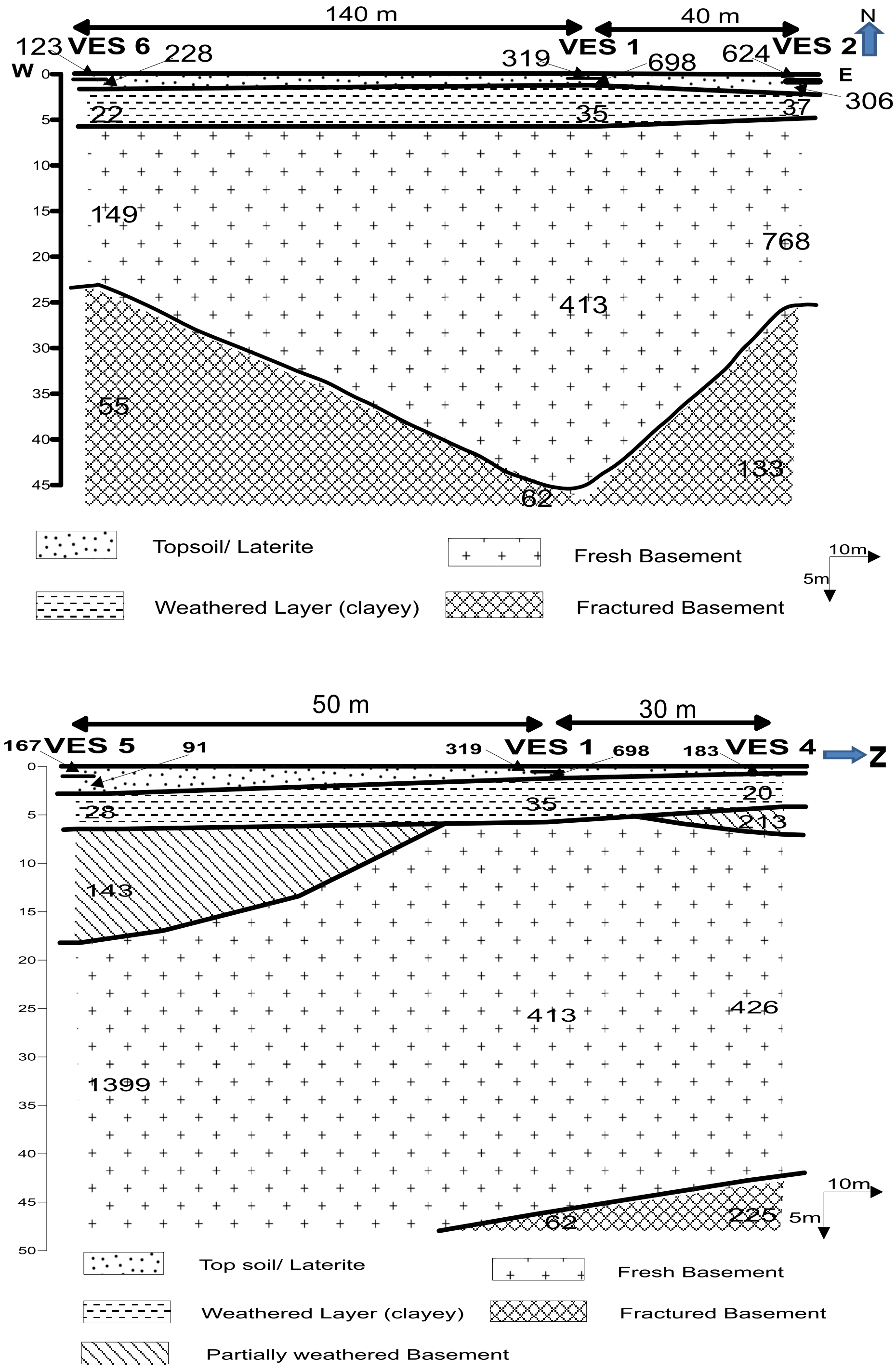


Fig 8: Geoelectric sections along: (a) East-West and (b) South-Northern cross sections

Conclusion

Very Low Frequency-Electromagnetic (VLF-EM) and Electrical Resistivity (ER) methods have been used to investigate the causes of the borehole failure in a typical basement complex area of Ibadan, South–western, Nigeria, where three consecutive failed boreholes have earlier been drilled. VLF-EM and ER data were acquired and interpreted based on the distribution of geoelectrical parameters in the study area. VLF-EM data were interpreted on the threshold of positive peaks real filtered amplitude of 20% typical of thick overburden and fractured basement in the area. The result shows that the three failed boreholes were located on the unfissured fresh basement rock. The identified fractured and conductive zones were further investigated using Vertical Electrical Soundings (VES). The VES data were presented as sounding curves and interpreted as geoelectric units. The VES sections were correlated with the borehole lithological logs. Based on our investigation, the only aquifer unit identified in the area is fractured basement. VES 2 and VES 6 were drilled to a maximum depth of 45.0 m and the observed yield were respectively 2300 and 4400 litres/h after pump testing.

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