PRE-CONSTRUCTION INTEGRATED GEOPHYSICAL INVESTIGATION OF THE PROPOSED THEATRE AND MEDIA ARTS COMPLEX WITHIN FEDERAL UNIVERSITY OYE-EKITI, EKITI STATE, SOUTHWESTERN, NIGERIA

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Abstract: Integrated Geophysical investigation involving the Very Low Frequency Electromagnetics (VLF-EM), Magnetics and Electrical Resistivity methods were carried out around the proposed Theatre and Media Arts Complex within the Federal University Oye-Ekiti. The study is aimed at assessing the competence of the subsurface materials for the proposed building. Six (6) traverses were established in the area in the W-E and N-S directions along which the VLF-EM, Magnetics and Vertical Electrical Sounding (VES) data were acquired. The dipole-dipole data were acquired along four separate traverses. Nineteen (19) Schlumberger Vertical Electrical Sounding (VES) stations were occupied within the study area. VLF-EM filtered real positive peak anomalies were identified in the area with the highest amplitude observed along traverse 2 at 82.5 m. The magnetic profiles identified high and low magnetic anomalies in the area with the major EM anomaly in traverse 2 revealed as high magnetic intensity. KH curve type is the dominant in the area and four major geoelectric layers were delineated in the area namely the topsoil (composed of clay, sandy clay, clayey sand and laterite), laterite, weathered layer (composed mainly of clay and sand) and fractured/fresh basement bedrock. The depth to bedrock ranges from 1.9-26.4 m. The lateritic layer below the topsoil is very thick beneath VES 6 (12.1 m). The Dipole-Dipole inverted 2-D resistivity image shows suspected basement depressions, fractures or lithological boundary which correlates with the results obtained from the other geophysical techniques. The resistivity and thickness maps of the area show that the topsoil is weak (clayey) in the northern and southern parts, lateritic in the central part, although generally thin (<1.5 m) and that the materials above the weathered layer (where they are lateritic) should be able to bear the load of the building even though it is rarely greater than 4 m in thickness. It could be deduced however, that the central portion of the study area which is expected to host the foundation of the proposed building is competent for the building construction purpose.

Keywords: Competence, foundation, VLF-EM, magnetics, electrical resistivity methods

Introduction

Engineering Geophysics involves the application of geophysical methods to civil engineering construction project (Olorunfemi and Mesida, 1987) and therefore, has found useful application in the construction of civil engineering structures. These civil engineering structures such as Buildings, Dams, Highways, Bridges, etc are constructed on a daily basis and are important in the socio-economic development of an area, state, nation and the world at large. They are usually constructed on land or on water but in either case, they are founded either on soils (which are usually weathering product of the rock type present in the area or deposited sediments) or directly on the rock. The soils may either be competent or incompetent while the rock may either be fractured or not. Therefore, care must be taken in order to host civil engineering structures especially heavy and/or high-rise ones on competent soils and unfractured rock.

The most important civil engineering structure to man is the building which provides shelter as its primary function and used for business, comfort and public utilities (Adeyemo *et al.*, 2014) as its secondary function. Nevertheless, the increase in the incessant failure of buildings has recently been attributed to subsurface geological problems (Egwuonwu and Sule, 2012; Adeyemo *et al.*, 2014) by Geologists and Geophysicists. Therefore, there is need to investigate the subsurface of any site which would host the foundation of the building and bear its load prior to construction (Akintorinwa and Adeusi, 2009). The information obtained from such study is necessary in order to provide subsurface and aerial information that normally assist Civil Engineers, Builders and Town Planners in the design and sitting of foundations for civil engineering structures (Omoyoloye *et al.*, 2008; Akintorinwa and Adeusi, 2009).

Geophysical investigations have been carried out over the years as a means to obtain subsurface information either prior to or after construction (Olorunfemi and Mesida, 1987; Akintorinwa and Adeusi, 2009; Ofomola *et al.*, 2009; Akintorinwa and Abiola, 2011; Bayode *et al.*, 2012; Egwuonwu and Sule, 2012; Adeyemo *et al.*, 2014). The use of integrated geophysical methods is rather acceptable as it assists in comparism of the subsurface information for correlation and to ascertain the existence of a particular geophysical anomaly. Therefore, integrated geophysical methods involving Magnetics, VLF-EM and Electrical Resistivity methods were employed in this study as pre-construction survey techniques for a proposed building complex as such investigation involving foundation studies helps the civil engineers to know the depth at which the foundation could be placed and this will help in reducing the failure of the proposed civil structures and prevent enormous economic loss that always accompanies such failure.

Materials and Methods

Description of the study area

The study area is the site for the proposed Theatre and Media Arts Complex within the Federal University Oye-Ekiti, Ekiti State, Southwestern Nigeria. It is located beside the Faculty of Science (Phase II) Complex, within the geographic grids of Eastings 755290 and 755698 mE and Northings 860074 and 860483 mN (Fig. 1). It is accessible by road from Phase I of the campus. The study area is located within the sub-equatorial climate belt of tropical rain-forest vegetation where the average annual rainfall is 1333 mm and the mean annual temperature is 27^0C (Owoyemi, 1996, Balogun, 2000). The topographic elevation of the area is generally undulating ranging from 520 to 540 m. The study site is gently sloping to the north. Federal University Oye-Ekiti is underlain by the Precambrian basement complex rocks of Southwestern Nigeria (Rahaman, 1988). The major lithological rock unit present within the study area is Migmatite (Fig. 2).

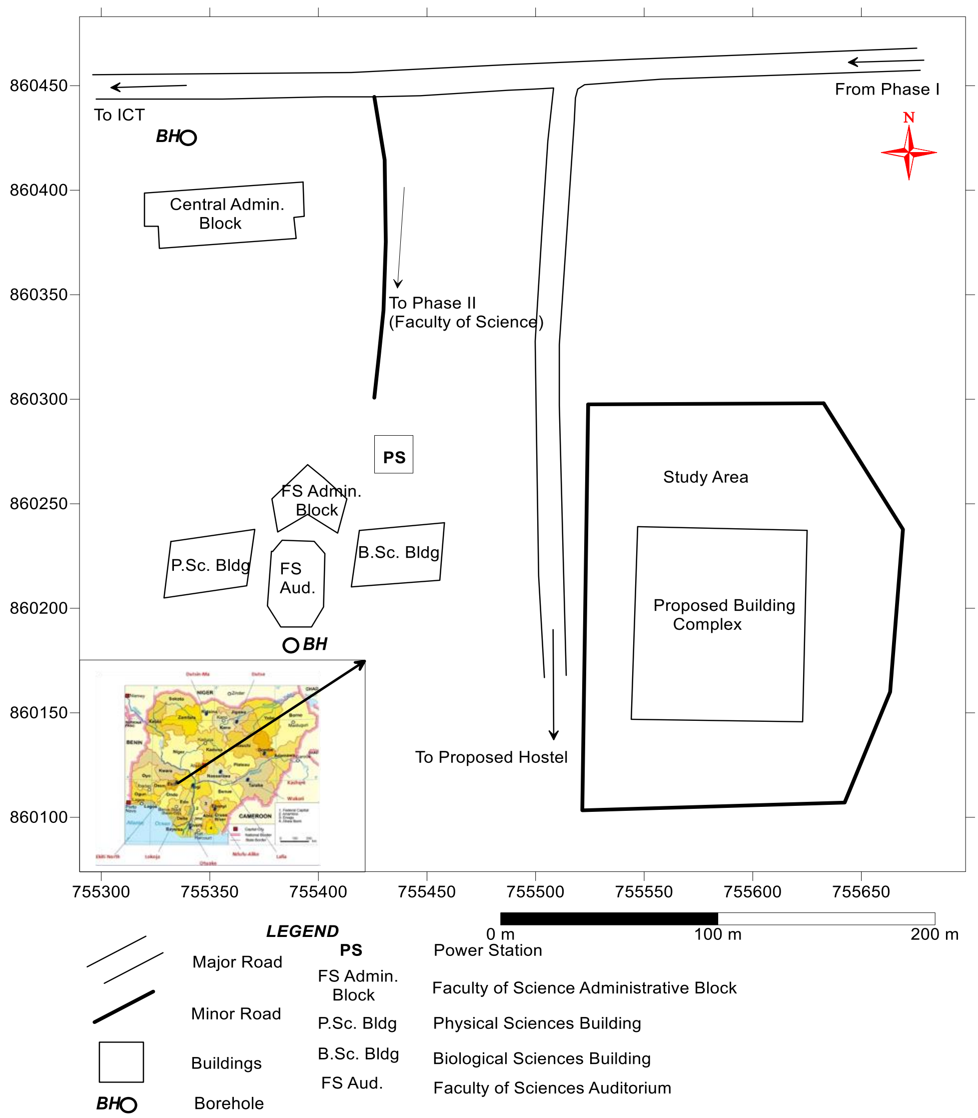


Fig. 1: Base map of the study area (Inset: Map of Nigeria)

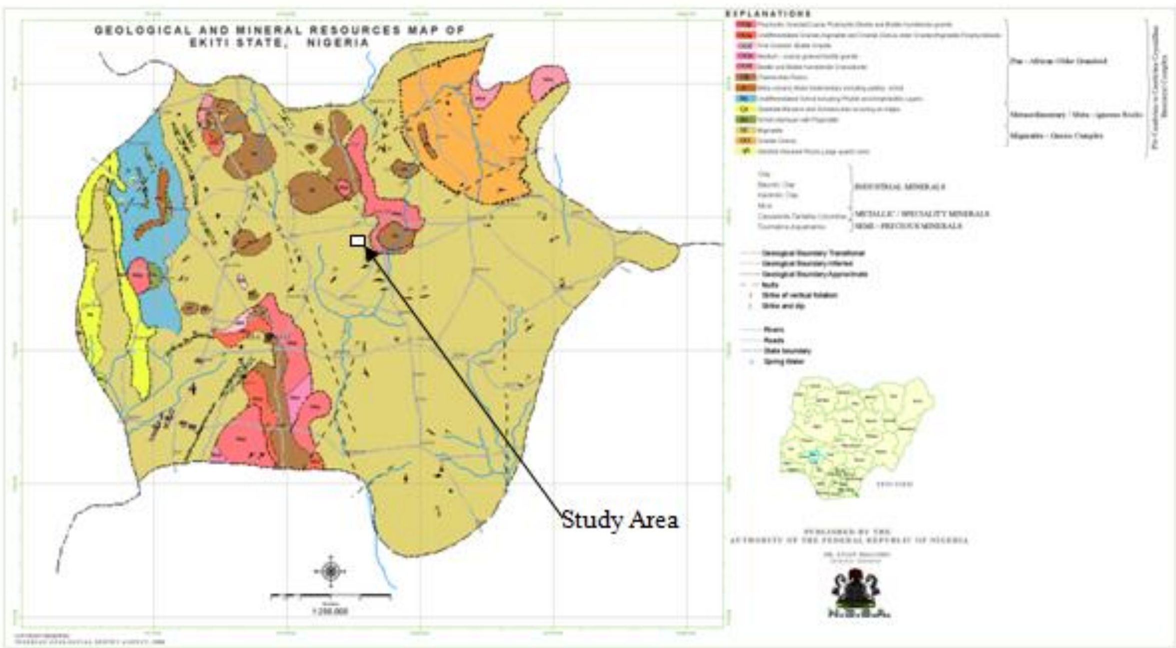


Fig. 2: Geological map of Ekiti showing the study area (after NGSA, 2006)

Methodology

The methodology adopted in this study involved the use of VLF-EM, Magnetics and Electrical Resistivity geophysical methods of investigation. Six (6) traverses were established in the study area in the W-E (Traverses 1 – 4) and N-S (Traverses 5 and 6) directions with the maximum having a length of 185 m. VLF-EM and Magnetics data were obtained along these six traverses (Fig. 3).

The VLF-EM method in principle utilizes transmitters which are primarily used for marine and military navigations and are operating between 15-30 kilohertz (kHz) as the primary EM wave source (Telford *et al.*, 1990). The ABEM WADI VLF-EM receiver equipment was used and data were obtained at station separations of 5 m and 10 m along traverses 1 – 4 and traverses 5 – 6, respectively (Fig. 3). The transmitter's EM wave adopted has frequency of 18.3 KHz and signal strength of 15. Although both the real and quadrature components of the VLF-EM were measured; the real component data, which are usually more diagnostic of linear features, were processed for qualitative interpretation. The VLF data measured was subjected to Fraser (1969) filtering to increase the signal to noise ratio of the data set and enhance the anomaly signature. The Fraser Filter (Q) was computed using a filter operator as shown in the relation below:

$$Q = (Q_3 + Q_4) - (Q_1 + Q_2) \ldots\ldots\ldots\ldots\ldots (1)$$

Where: Q is the filtered EM data called Q-factor and the subscripts are station positions.

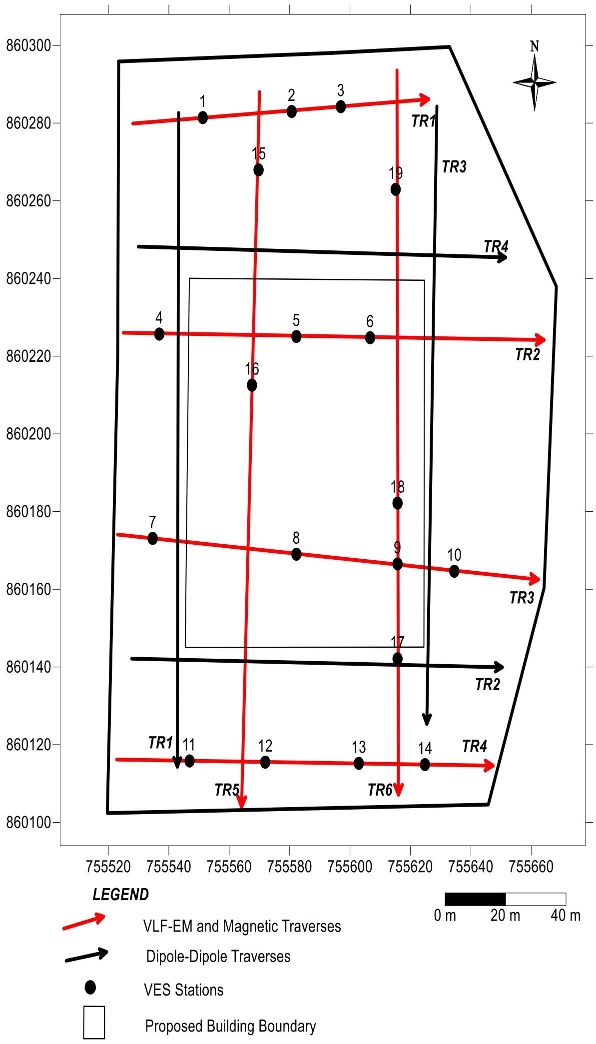


Fig. 3: Data acquisition map of the study area

The raw real data and Q-factor were plotted against their respective station distances to generate EM profiles and 2-D models of the data were obtained by iterating with KH-Ffilt software (Pirttijärvi, 2004).

The ground magnetic survey involved measurement of total field component of the earth's magnetic field (Telford *et al.*, 1990). The GSM-8 Proton Precession Magnetometer with its antenna and measuring tape were used to obtain the magnetic data at station positions along the profiles with intervals of 5 m and 10 m as adopted in the electromagnetic survey (Fig. 3). The closely spaced stations adopted for magnetic survey allow high resolution of near-surface geologic material. Base stations were established before the commencement of the measurement and after the measurement in order to correct for diurnal and offset effects (Telford *et al.*, 1990). Ten (10) base station readings were taken and the average was adopted. The obtained data were processed to obtain the residuals of the relative magnetic readings which was plotted against distance and presented as profiles.

The electrical resistivity method adopted involved the passage of electric currents into the ground through two electrodes (current electrodes) and the resulting potential difference measured through two other electrodes (potential electrodes). The potential electrodes may be placed either within or outside the current electrodes depending on the type of array adopted. The Ohmega resistivity meter with complete accessories was used and the Vertical Electrical Sounding (VES) and Combined HP+VES techniques (Keary *et al.*, 2002) were employed. Nineteen (19) Schlumberger Vertical Electrical Soundings (VES) were carried out within the study area using maximum current electrode separation (AB) of 130 m. The dipole-dipole (Combined HP+VES) data were acquired along four separate traverses using the electrode separation, "a" of 5 m along traverse 2 and 4 (W-E) and 10 m along traverse 1 and 4 (N-S) (Fig. 3) with an expansion factor, n, ranging from 1 to 5. The VES data were plotted as depth sounding curves using the bi-log paper and interpreted quantitatively by the method of partial curve matching using the two-layer master and auxiliary curves of Orellana and Mooney, 1966. The final subsurface geoelectrical models were obtained with the aid of the computer-assisted iteration technique, using WinResist Software (Vander Velpen, 2004). The Dipole-Dipole configuration data which measures the lateral and vertical variations in the ground apparent resistivity values were inverted for true subsurface resistivity using DIPRO inversion algorithm software (Kigam, 2001) and presented as pseudosections.

Results and Discussion

VLF-EM anomaly profile

The geophysical results obtained from the six (6) traverses were interpreted based on their anomaly signatures. The VLF-EM positive peaks of the *Filtered real* (Q-factor) anomaly which coincide with the S-shaped anomaly of the *raw real* plot (Sinha, 1990) are considered as conductive overburden or structurally weak (fractured/faulted basement) zones in the area. Major and minor peaks were identified in the study area. Prominent (major) VLF-EM filtered real positive peak anomalies in the study area were identified along traverse 2 at distance of 82.5 m, traverse 3 at 12.5 m and traverse 4 at 22.5 m shown as yellowish green-yellow-reddish colouration on their respective 2-D models (Figs. 4a–f). These anomalous zones are interpreted as areas of thick overburden, fractured basement zones and/or lithological boundary in the study area. Other minor VLF-EM filtered real positive peak anomalies were identified along the six traverses on which Vertical Electrical Soundings were either carried out or not (Figs. 4a – f). These minor zones are usually areas of thin conductive overburden shown as green colouration on the 2-D models.

Intermediate between the conductive zones are the resistive zones which appears as blue colour (Kaikkonen and Sharma, 1997). Threshold frequency amplitude of the filtered real VLF Response of 15 % was used to differentiate the major conductive zones from the minor ones. The highest amplitude of the filtered real response in the study area is the one observed along traverse 2 at 82.5 m (Fig. 4b).

Magnetic profiles

The magnetic profiles were interpreted qualitatively using the three point average obtained from the residual of the Relative Magnetic Intensity. Prominent magnetic anomalies identified as high and low magnetics which could be indicative of weak zones, faults, fractures or lithological discontinuities were delineated within the study area (Figs. 4a–f). The magnetic profiles, however, is a better indicator of the basement topography (relief) showing major high relief (magnetic intensity) between distances 10 and 35 m and low relief between 50 and 65 m on traverse 1; high magnetic intensity between distances 15 and 28 m and 75 – 106 m on traverse 2; magnetic highs around 10 m and 80 – 107 m and magnetic lows between 20 and 45 m on traverse 3; magnetic lows between 20 and 50 m on traverse 4; magnetic lows between distances 10 – 35 m and 110 – 140 m on traverse 5; magnetic highs between 50 and 80 m and magnetic lows between 90 and 140 m on traverse 6 (Figs. 4a – f). The magnetic anomaly observed between 50 and 140 m along traverse 6 is typical of a thin dyke. The high magnetics and the thin dykes in the study area are indicative of the presence of near-surface geologic feature or basement while the low magnetics could be indicative of clayey overburden, deep-seated fractures, faults, thick overburden or lithological boundary in the study area.

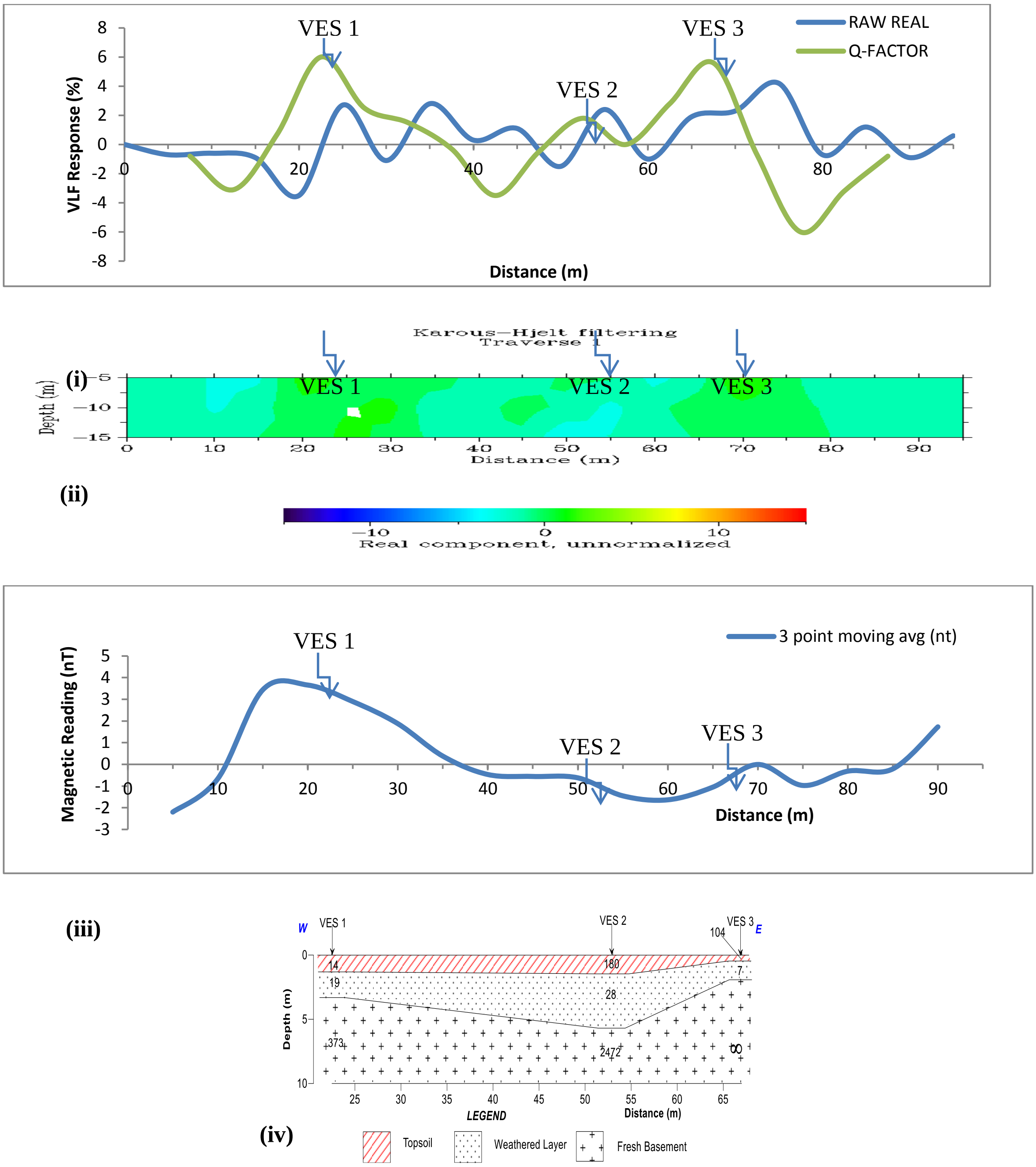


Fig. 4a: Correlation of geophysical results beneath traverse 1

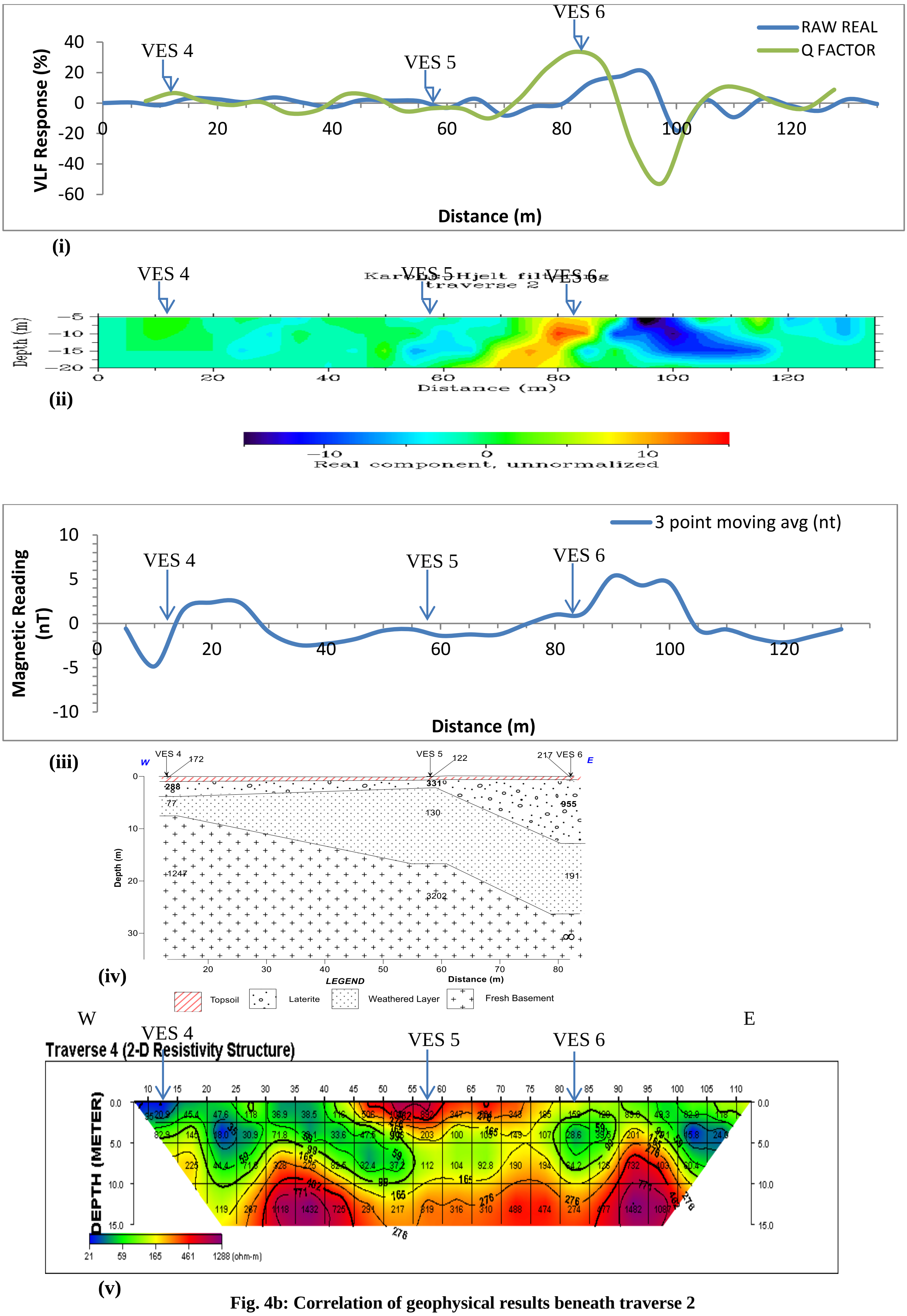


Fig. 4b: Correlation of geophysical results beneath traverse 2

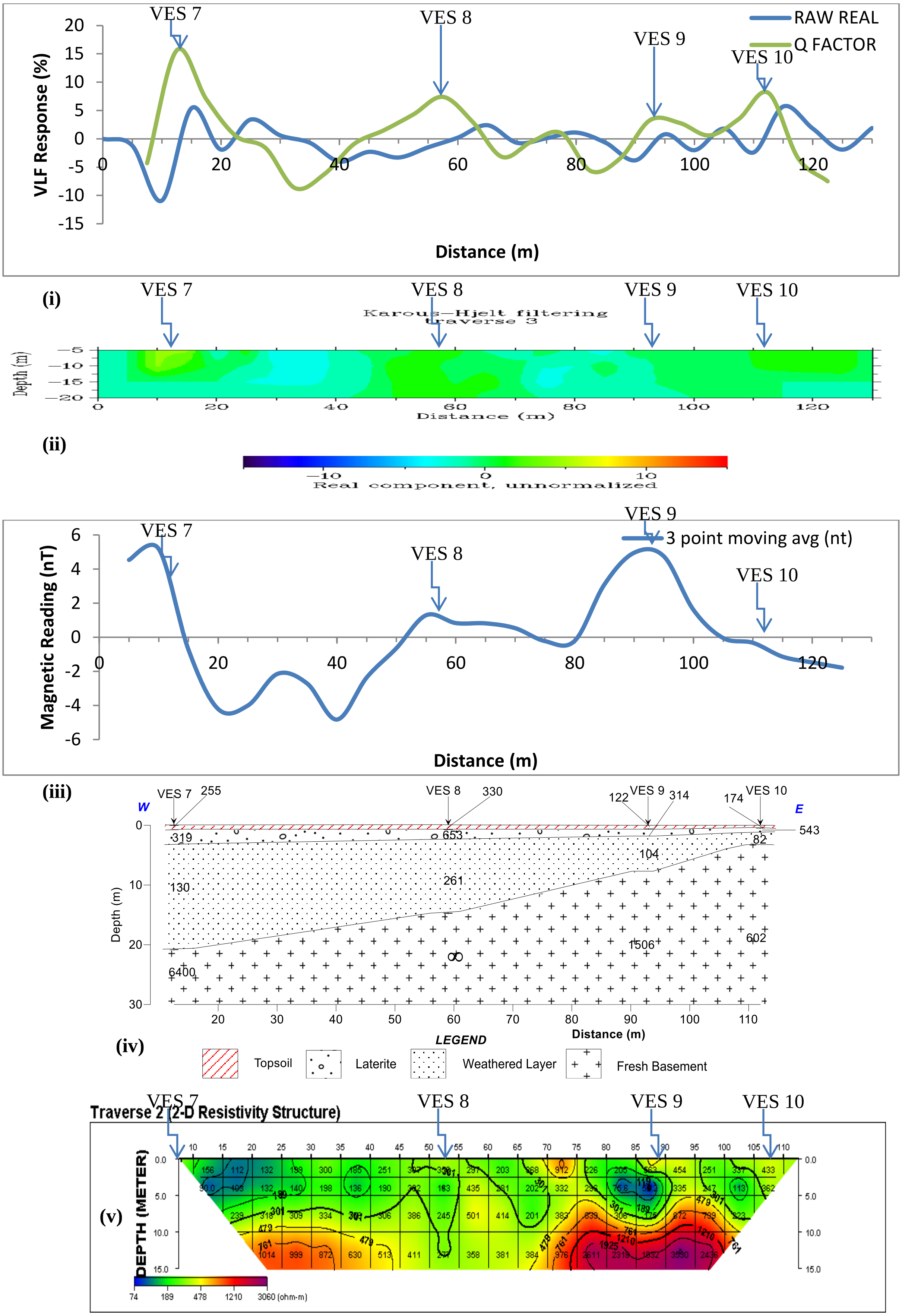


Fig. 4c: Correlation of geophysical results beneath traverse 3

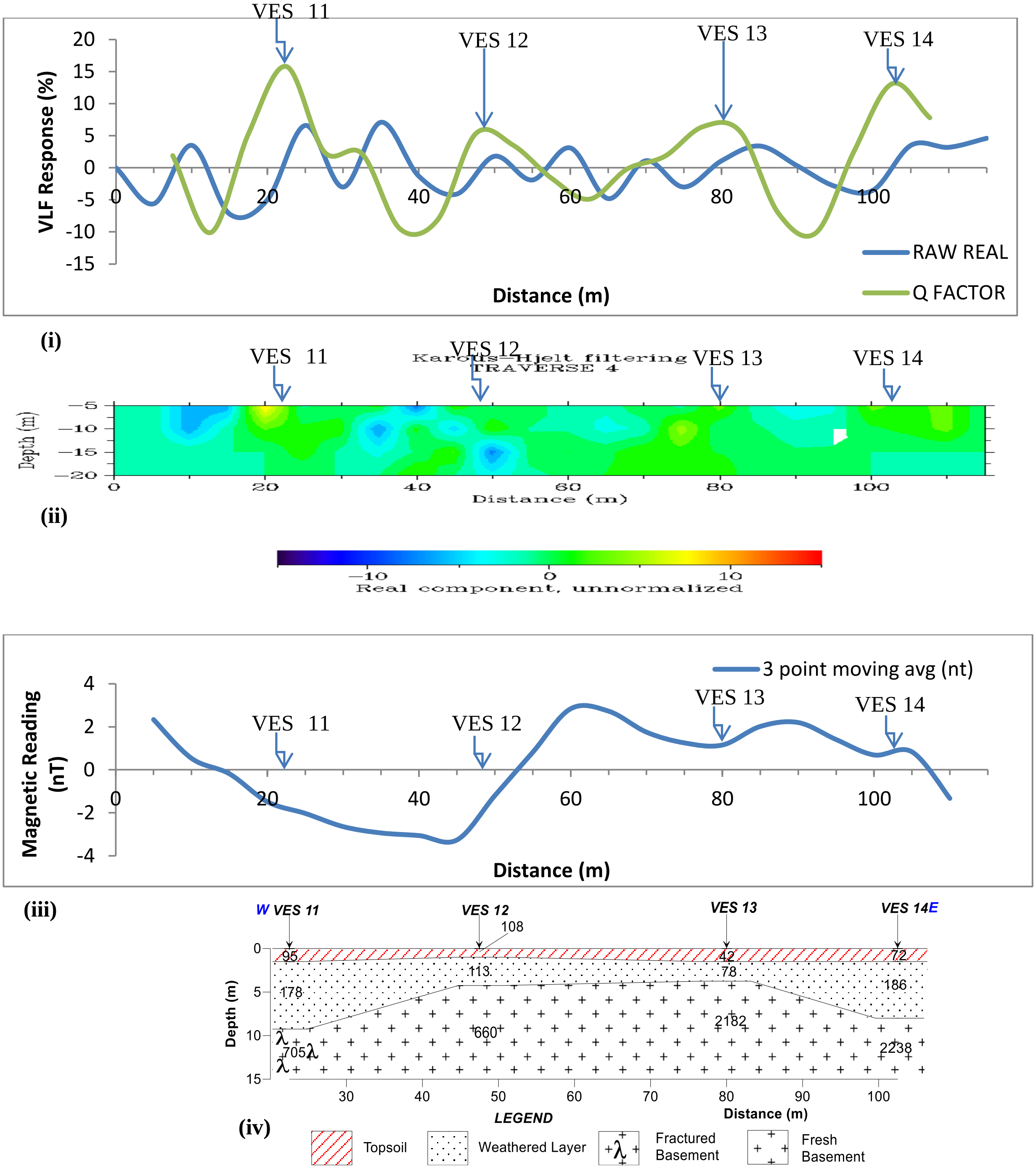


Fig. 4d: Correlation of geophysical results beneath traverse 4

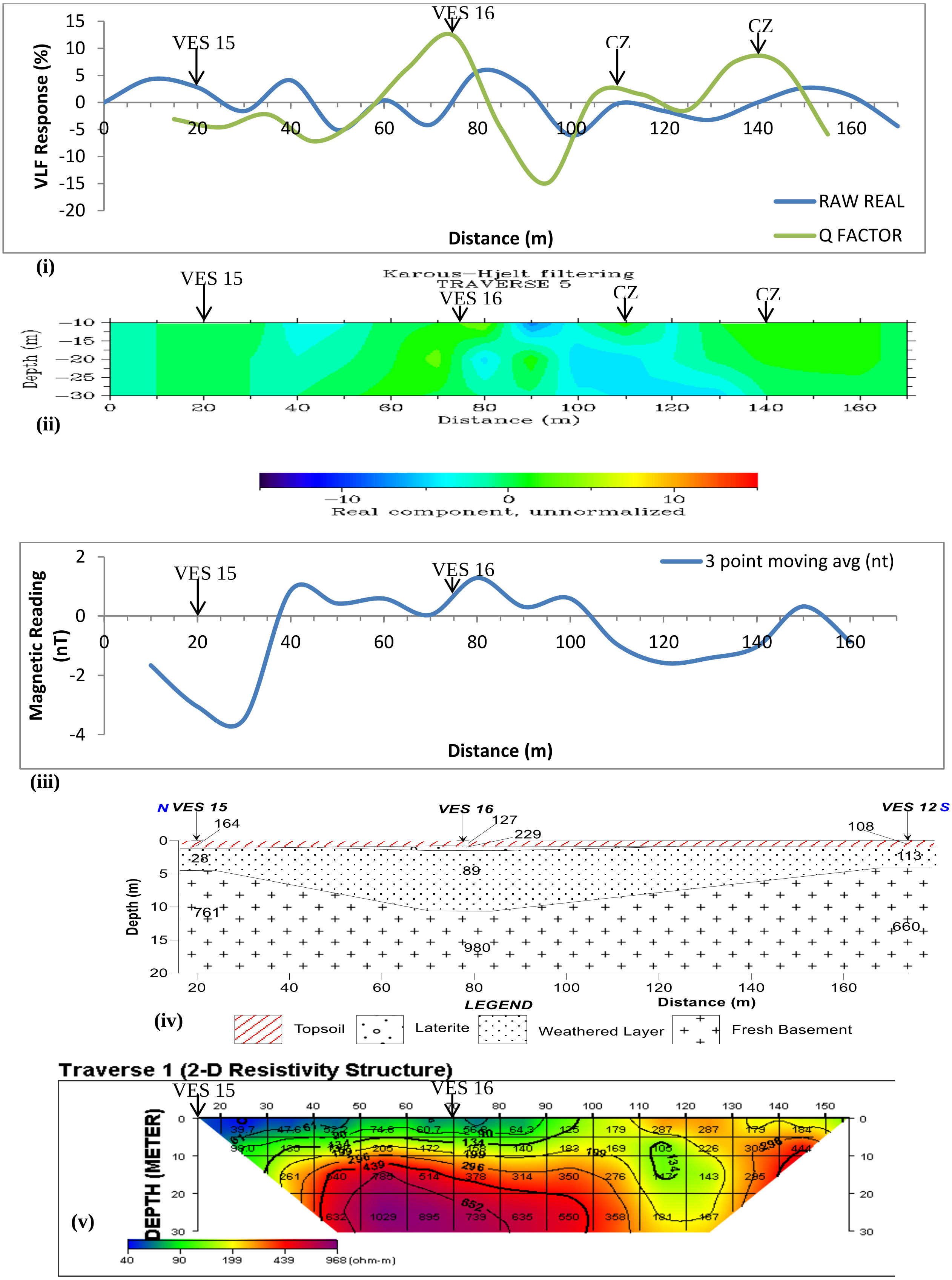


Fig. 4e: Correlation of geophysical results beneath traverse 5

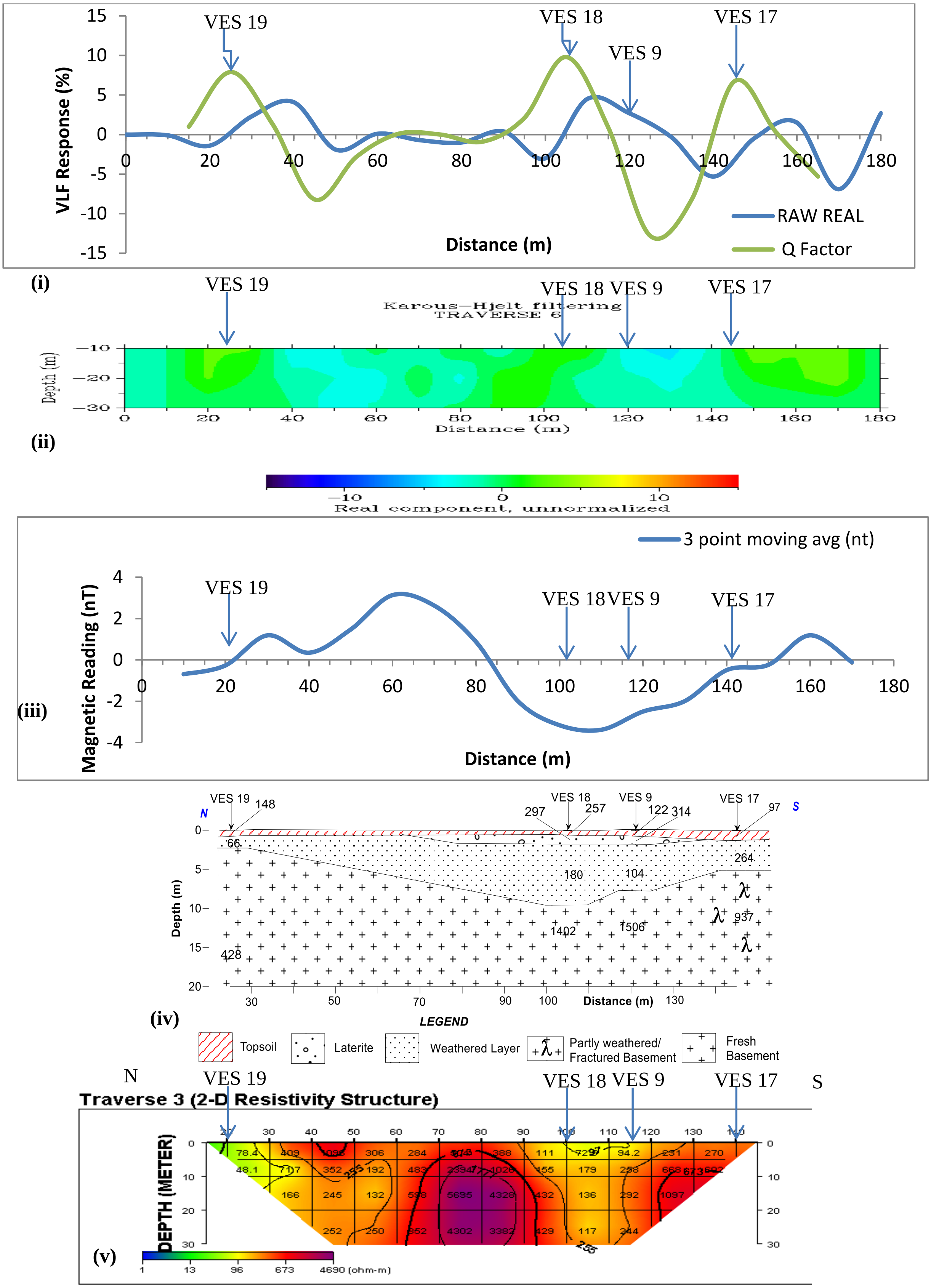
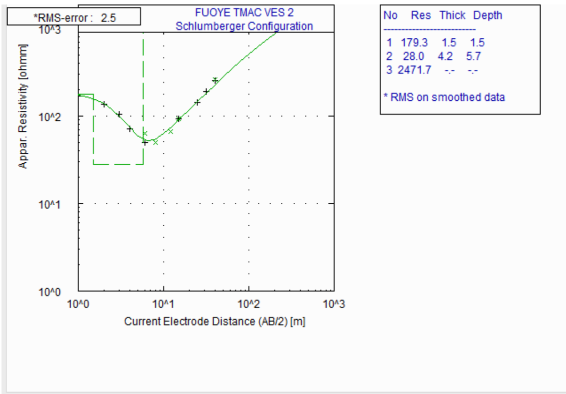
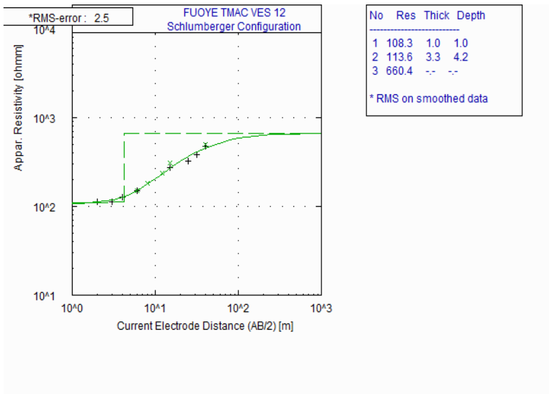


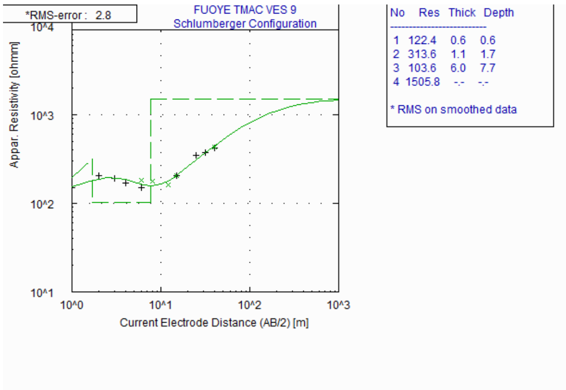
Fig. 4f: Correlation of Geophysical Results beneath Traverse 6



(a) Typical H Curve Type



(b) Typical A Curve Type



(c) Typical KH Curve Type

Fig. 5: Typical curve types obtained in the study area

Vertical electrical sounding (VES) curves

The electrical resistivity investigation was carried out in order to delineate the nature of the subsurface layers and characterize them so as to know their strength for civil engineering structures. The VES curves obtained within the study area are the three-layer H, A and four-layer KH curve types with the KH-types being dominant. The H curve type makes up 21%, A curve - 32% and KH makes up 47% of the total curve type within the study area (Table 1). Typical curve types obtained within the study area are shown in Figs. 5a – c while the summary of the VES results are presented in Table 2.

Table 1: Percentage curve types obtained within the study area

Curve type	No. obtained within the study area	Percentage
H	4	21%
A	6	32%
KH	9	47%
Total	**19**	**100%**

Geo-electric sections

Geoelectric sections were drawn in the W-E and N-S directions within the study area (Fig. 4a (iv)-f (iv)). The sections generally reveal three to four geoelectric layers within the area which are: the topsoil, laterite, weathered layer and the fractured/fresh basement bedrock. The topsoil varies in resistivity from 14 to 330 Ωm with thickness range of between 0.5 and 1.5 m. It is composed of clay, sandy clay, clayey sand and laterite. The underlying lateritic layer varies in resistivity from 229 to 955 Ωm and its thickness range between 0.6 and 12.1 m. The weathered layer varies in resistivity from 7 to 264 Ωm and its thickness ranges between 1.4 and 17.5 m. It is composed mainly of clay and sand. The bedrock which is fractured beneath VES 11 and 17 varies in resistivity from 373 Ωm to infinity (∞) with depth to bedrock ranging between 1.9 and 26.4 m. The low basement resistivity (< 1000 Ωm) which is largely due to screening effect (Ojo *et al.*, 2015) is observed in places because of the conductive layer overlying it. Evaluation of the resistivity coefficient of the subsurface layers shows that the bedrock is fractured beneath VES 11 and 17 (Bhattacharya and Patra, 1968; Olayinka, 1996; Bayewu *et al.*, 2012). The high resistivity variation of the topsoil show high degree of inhomogeneity in the topsoil. The topsoil is generally thin (not greater than 1.5 m), the underlying lateritic layer is very thick beneath VES 6 with a thickness of 12.1 m, and the bedrock shows depression beneath VES 2, 5, 6, 7, 8, 9, 11, 14, 16 and 18. The high resistivity portions of the topsoil, indicative of laterite and portions where the topsoil is underlain by laterite (majorly beneath traverse 2 and 3) (Figs. 4b (iv) and 4c (iv)) are classified as competent portions of the study area which may be able to withstand the bearing load of the building.

Table 2: Summary of VES interpretation

VES Station	CT	NL	Resistivity (Ohm-m)	Depth (m)	Lithological Equivalence
1	A	3	14/19/373	1.3/3.3/-	Topsoil/Weathered Layer/ Fresh Basement
2	H	3	180/28/2472	1.5/5.7/-	Topsoil/Weathered Layer/ Fresh Basement
3	H	3	104/7/10658	0.5/1.9/-	Topsoil/Weathered Layer/ Fresh Basement
4	KH	4	172/288/77/1247	1.0/3.8/7.5/-	Topsoil/Laterite/Weathered Layer/Fresh Basement
5	KH	4	122/331/130/3202	0.6/2.2/16.6/-	Topsoil/Laterite/Weathered Layer/Fresh Basement
6	KH	4	217/955/191/19140	0.7/12.8/26.4/-	Topsoil/Laterite/Weathered Layer/Fresh Basement
7	KH	4	255/319/130/6400	0.8/3.3/20.8/-	Topsoil/Laterite/Weathered Layer/Fresh Basement
8	KH	4	330/653/261/10243	0.7/2.2/14.7/-	Topsoil/Laterite/Weathered Layer/Fresh Basement
9	KH	4	122/314/104/1506	0.6/1.7/7.7/-	Topsoil/Laterite/Weathered Layer/Fresh Basement
10	KH	4	174/543/82/602	0.5/1.1/3.3/-	Topsoil/Laterite/Weathered Layer/Fresh Basement
11	A	3	95/178/705	1.5/9.2/-	Topsoil/Weathered Layer/ Fractured Basement
12	A	3	108/113/660	1.0/4.2/-	Topsoil/Weathered Layer/ Fresh Basement
13	A	3	42/78/2182	1.5/3.7/-	Topsoil/Weathered Layer/ Fresh Basement
14	A	3	72/186/2238	1.5/8.0/-	Topsoil/Weathered Layer/ Fresh Basement
15	H	3	164/28/761	1.2/4.6/-	Topsoil/Weathered Layer/ Fresh Basement
16	KH	4	127/229/89/980	0.8/1.5/10.6/-	Topsoil/Laterite/Weathered Layer/Fresh Basement
17	A	3	97/264/937	1.3/5.1/-	Topsoil/Weathered Layer/ Fractured Basement
18	KH	4	257/297/180/1402	0.5/1.7/9.5/-	Topsoil/Laterite/Weathered Layer/Fresh Basement
19	H	3	148/66/428	0.7/2.3/-	Topsoil/Weathered Layer/ Fresh Basement

CT = Curve Type; NL = Number of Layers

Dipole-dipole pseudosections

The dipole-dipole pseudosections (2-D resistivity structure) show the subsurface images inverted from the field data and its calculated theoretical data pseudosection revealing both lateral and vertical variations in ground apparent resistivity values of the subsurface. The 2-D resistivity structures delineated three major subsurface layers: the topsoil/laterite, the weathered layer and the fractured/fresh basement bedrock. The traverse 4 which is correlated with traverse 2 of the other geophysical methods (Fig. 4b (v)) shows inhomogeneity within the topsoil. It reveals high resistivity layer which could be indicative of laterite, reaching a depth of about 5 m beneath the sub-surface and basement depression between distances 45 and 88 m. The 2-D resistivity structure beneath traverse 2 (correlated with traverse 3) show pockets of moderately resistive/lateritic topsoil between 70 and 75 m and 85 – 95 m (Fig. 4c (v)). Generally, the overburden is moderately thick (at least 10 m) on this traverse with basement depression between distances 40 and 70 m. The resistivity image beneath Traverse 1 (correlated with traverse 5) shows inhomogeneity of the subsurface (Fig. 4e (v)). It reveals low resistivity topsoil at the northern flank and moderately resistive topsoil from about 95 – 150 m (southern flank). Basement depression was observed beneath the traverse between distances 110 and 130 m which could be typical of fractured basement and could be inimical to the engineering structure to be constructed in the study area. The resistivity image beneath traverse 3 (correlated with traverse 6) shows moderately high resistivity of the subsurface and a bouldery structure was identified between distances 60 and 95 m (Fig. 4f (v)). This eastern portion of the study area would be good for the building construction because of its resistive nature. Nevertheless, a low resistivity zone is observed between distances 100 and 112 m typical of a fracture/lithological boundary.

Synthesis of results

The prominent/major VLF anomalies beneath traverse 1 are seen as low resistivity topsoil/weathered layer beneath VES 1 and 3 while the minor anomaly shows basement depression, as also indicated by the low magnetic intensity beneath VES 2 (Fig. 4a). The conductive zones identified on the VLF-EM and Magnetics at about 70 – 90 m on traverse 2 corresponds to the thick overburden seen on the geoelectric section beneath VES 6 which in turn correlates with that observed on the 2-D Dipole-Dipole pseudosection (Fig. 4b). The highest amplitude conductive zone identified on the VLF-EM profile for traverse 3 indicates a low basement relief or thick overburden on the Magnetics, geoelectric section and the Dipole-Dipole 2-D resistivity structure (Fig. 4c) especially between distances 40 and 70 m. The basement depression identified beneath VES 11 (with its corresponding basement fracture) and VES 14 on traverse 4 account for the high amplitude of the VLF-EM identified on the profile and the magnetic low of the magnetic profile along this traverse (Fig. 4d). The conductive zones identified on the EM profiles and 2-D models beneath traverse 5 and 6 (N-S) correlate with that observed on the Magnetics, geoelectric section and the Dipole-Dipole 2-D image (Figs. 4e and 4f). These zones are either conductive overburden or basement depressions. The magnetic anomaly typical of a thin dyke along traverse 6 corroborates the bouldery structure identified on the resistivity image (Fig. 4f).

Iso-resistivity and isopach map of the topsoil

Figures 6 and 7 shows the iso-resistivity and isopach maps of the topsoil. The topsoil resistivity varies from 14-330 Ωm. The resistivity is high (160-320 Ωm) in the central portion of the study area extending eastward and westward (around Traverse 2 and 3) and low (40 – 120 Ωm) in the south and northern part (around Traverse 1 and 4). The high resistivity zone of the topsoil is lateritic and indicative of competent topsoil (Akintorinwa and Adeusi, 2009) while the low resistivity portions are clayey and depicts incompetency of the topsoil. The topsoil thickness varies between 0.5 and 1.5 m. The isopach map of the topsoil shows that it is relatively thick (0.85 - 1.5 m) in the northwestern part and in the southern part and thin (0.5 – 0.85 m) in the northeastern part and central portion. Areas with relatively thick topsoil and high resistivity may be able to carry the load of the building. Nevertheless, areas with high topsoil resistivity in the study area shows thin topsoil (Figs. 6 and 7).

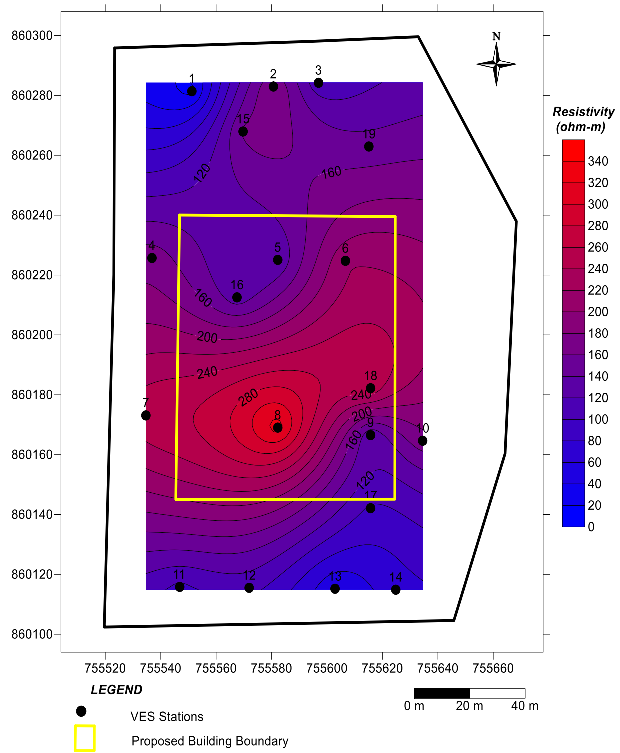


Fig. 6: Isoresistivity map of the topsoil in the study area (TMAC, FUOYE)

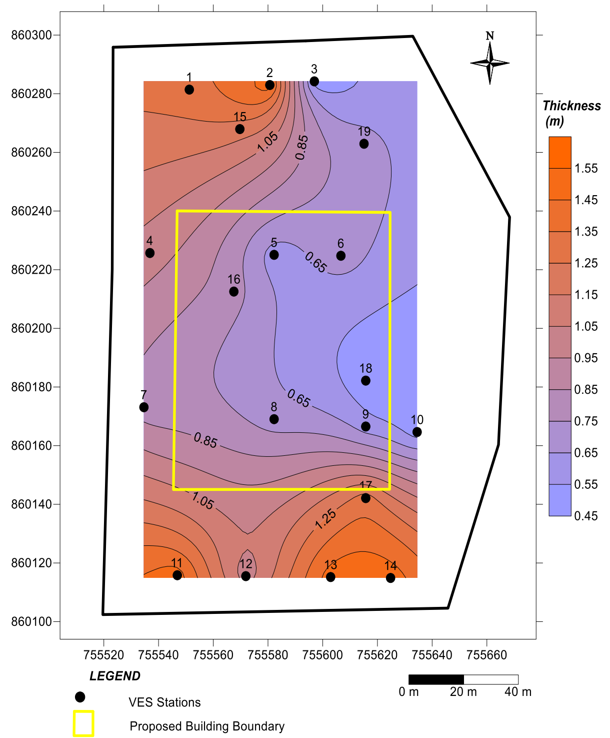


Fig. 7: Isopach map of the topsoil in the study area (TMAC, FUOYE)

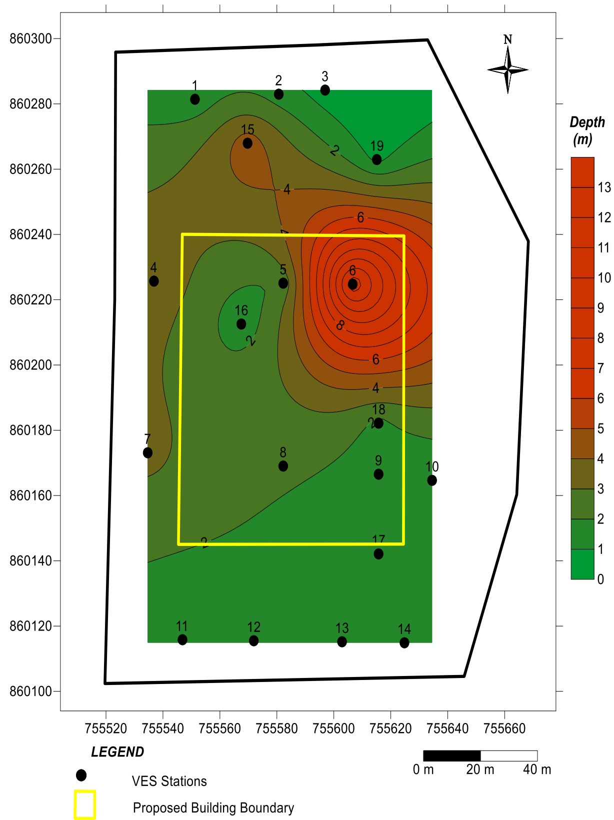


Fig. 8: Depth to weathered layer map of the study area (TMAC, FUOYE)

Depth to weathered layer map

Map showing the thickness of all materials on the weathered layer was generated (Fig. 8). The thickness of all materials above the weathered layer (topsoil and underlying laterite in places) varies between 0.5 and 12.8 m. The depth to weathered layer map shows that the northern/northeastern part of the proposed building has thick overburden (3 – 12.8 m) especially beneath VES 6. Generally, most part of the area has this overburden thickness within the range of 2 - 3 m. Although, the southwestern part of the area with high topsoil resistivity (Fig. 6) does not have appreciable thickness, nevertheless, the materials above the weathered layer may be able to bear the load of the building as a result of the lateritic nature of some of the areas either at the topsoil or beneath it.

Conclusions

The results of the geophysical investigations carried out around the proposed Theatre and Media Arts Complex within the Federal University Oye-Ekiti reveals the presence of moderate conductive zones in the area by the VLF-EM and Magnetic profile results obtained along the established traverses. The conductive zones correspond to low resistivity zones or thick overburden above the basement or fractures as revealed by the geoelectric sections. They also appear as basement depressions, suspected fractures, faults and/or lithological boundary on the Dipole-Dipole 2-D resistivity images. The topsoil iso-resistivity and isopach maps shows that the topsoil is weak (clayey) in the northern and southern parts, lateritic in the central part (also underlain by laterite) and it’s generally thin (<1.5 m) especially in the central part of the study area. The depth to weathered layer map shows that the materials above the weathered layer may be able to bear the load of the building where they are lateritic even though it is rarely greater than 4 m.

Therefore, based on the results obtained from this study, it could be deduced that the central portion of the study area (as seen beneath traverses 2 and 3 and central parts of traverses 5 and 6) which is expected to host the foundation of the proposed building is lateritic and the proposed portion of the site for the construction of Theatre and Media Arts complex in Federal University Oye-Ekiti is fairly competent for the building construction purpose. Moreover, the uneven nature of the area has to be considered in the design of the foundation (Akintorinwa and Adeusi, 2009) and a raft foundation could be used for the building.

Conflict of Interest

Authors declare that there are no conflicts of interest.

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