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Integrated geophysical investigation for post-construction studies of buildings around School of Science area, Federal University of Technology, Akure, Southwestern, Nigeria

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An integrated geophysical investigation involving ground magnetic, very low frequency (VLF-EM), and electrical resistivity methods using dipole–dipole array and schlumberger vertical electrical sounding (VES) techniques were conducted around School of Science Area Obanla, Federal University of Technology, Akure, for post construction studies in assessing building foundation integrity. Two traverses were established in approximately E-W direction of length 170 to 200 m and station interval of 10 m, along which VLF-EM, ground magnetic and dipole–dipole measurements were carried out. Sixteen VES stations were occupied within the study area. The VLF- EM data were interpreted using the Karous Hjelt (KH) package and inverted into its 2D Pseudosection. The VES data were quantitatively interpreted using the partial curve matching technique and 1-D forward modelling with WinResist 1.0 version software. The dipole-dipole data were inverted into 2-D resistivity images using the DIPPRO™ 4.0 inversion software. The VLF-EM result mapped three near surface conductive zones suspected to be fractures/faults which are inimical to foundation integrity. The magnetic results delineated series of bedrock ridges and depression. The VES result delineated four major Geo-electric layers within the study area. The topsoil, weathered layer, fractured bedrock and fresh bedrock. The top soil (resistivity varies from 47 to 490 Ωm and thickness ranges from 0.7 to 3.9 m); weathered layer (resistivity varies from 13 to 207 Ωm and thickness ranges from 1.9 to 22.1 m), fractured bedrock (resistivity varies from 489.3 to 878.8 Ωm and thickness ranges from 2.4 to 19.6 m) and bedrock with resistivity 1094 to 96583 Ωm and depth to bedrock 2.6 to 24.8 m). The dipole-dipole results also mapped linear features (fracture) at distance 60 to 100 m and 100 to 120 m respectively along the two traverses. Then from the geophysical investigation, three major causes of potential failure in the area were identified, these are; failure due to lateral inhomogeneity of the subsurface layers, failure precipitated by differential settlement and failure initiated by geologic features such as fractures and faults.

Key words: Foundation integrity, lateral inhomogeneity, electromagnetic, resistivity, dipole-dipole.

INTRODUCTION

The rate of failed structures in Nigeria have increased in recent times (Oyedele et al., 2011). These structural failures are often times associated with the problem of poor quality of building materials, old age of buildings and improper foundation. In recent times, the land expanse in the Federal University of Technology, Akure have been

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opened to rapid development (Olayanju, 2011). Despite this rapid growth and development in the area, the impact of subsurface geologic structures in the area on the durability and easy maintenance of the erected structures have been seldom talked about. Vertical and near vertical cracks or discontinuities have been noticed in the walls of both old and recent buildings in the school (Bayode et al., 2012). This assertion can be attributed to the minimal attention towards the use of geophysics in foundation studies. In Engineering Geophysics and site investigation, structural information and physical properties of a site are sought (Sharma, 1997). This is so because the durability and safety of the engineering structural setting depend on the competence of the material, nature of the sub-surface lithology and the mechanical properties of the overburden materials.

Foundations are affected not only by design errors but also by foundation inadequacies such as sitting them on incompetent earth layers. When the foundation of a building is erected on less competent layers, it poses serious threat to the building which can also lead to its collapse. Therefore, there is need to evaluate the foundation integrity of the buildings around School of Science Area at the Federal University of Technology, Akure in terms of the subsurface structures and nature of the soil. This research is therefore targeted at revealing the use of Geophysical techniques as a reliable means of undertaking studies of construction sites as related to the Geologic nature of the environment thereby saving a lot of time and cost. Also, with the Science and Art of Geophysics, the basic problems of structures that have emerged problematic can be investigated and remediation actions can be taken.

Description of the study area

The area is located at Obanla, School of Science Area of the Federal University of Technology, Akure (FUTA), Ondo State, Nigeria. It is accessible through tarred road from Futa North gate. The site occupies an area of about 0.2 km. It lies between latitudes 7°18’21.3’’N and 7°18’47.1’’N (808000 and 808800) N in the Universal Transverse Mercator (UTM) scale, and longitudes 50°7’27.0’’ and 50°8’19.2’’ (734600 and 736200) E in the Universal Transverse Mercator scale (Figure 1).

Geology of the area

The campus is underlain by crystalline rock of the Precambrian basement complex of the Southwestern Nigeria (Rahaman, 1976; 1988). The lithologic units include migmatite gneiss complex, granitic gneiss and charnokites (Figure 2). Outcrops of biotite gneiss and granitic gneiss occur in some locations around the western part of the study area. Likewise some other boulders of granite and charnokites occur at the western street of the study area. The fractured bedrock generally occur in a typical basement terrain (Odusanya and Amadi, 1989) in tropical and equatorial regions, weathering processes create superficial layers, with varying degree of porosity and permeability. These geologic events gave rise to such structures as folds, faults and fractures that are geologically associated with zones of weakness. Geophysical methods can however, map these geologic structures; hence their application is employed to study the subsurface geology of the area in order to ascertain if there are geologic structure that can affect foundations or cause building collapse.

METHODOLOGY

Two traverses of about 170 and 200 m, respectively, were established in an approximate E-W direction (Figure 3). Three geophysical methods involving the magnetic, very low frequency electromagnetic (VLF-EM) and the electrical resistivity methods were adopted for this survey. The electrical resistivity method utilized the dipole-dipole profiling and the vertical electrical sounding (VES) techniques. The dipole-dipole survey was used to determine the lateral and vertical variation in apparent resistivity of the subsurface beneath the two established traverses. The VES involved the use of Schlumberger array. Sixteen sounding stations were occupied along the two established traverses and the current electrode spacing (AB/2) was varied from 1 to 65 m. The electrical resistivity data was processed by plotting the apparent resistivity values against the electrode spread (AB/2). This was subsequently interpreted quantitatively using the partial curve matching method and computer assisted 1-D forward modeling with WinResist 1.0 version software (Vander Velpen, 2004). The dipole-dipole data were inverted into 2-D subsurface images using the DIPPRO™ 4.0 inversion software (Dippro, 2000). 2-D electrical imaging of the subsurface was obtained using dipole-dipole configuration.

The inter-electrode spacing of 10 m was adopted while inter-dipole expansion factor (n) was varied from 1 to 10. Resistivity values were obtained by taking readings using the ohmega resistivity meter. The ground magnetic survey involved measurements of total field component of the earth’s magnetic field along the two traverses using GEM 8 proton precession magnetometer. The magnetic data were drift corrected and presented as profiles of relative magnetic intensity values against distance (Figure 4a, b). The automated Euler deconvolution software was used to estimate depth to basement along the traverses. The very low frequency electromagnetic data were processed by downloading the raw real and filtered real components from the Abem Wadi VLF-EM equipment. The data are presented as profiles (Figure 5a, b). The Abem Wadi measures the field strength and the phase displacement around the fracture zone. The EM data was interpreted and inverted into a 2-D section using the Karous-Hjelt filtering (Karous and Hjelt, 1983).

RESULTS AND DISCUSSION

Magnetic profiles

Along Traverse 1, the magnetic intensity contrast observed between -100nT and 700nT at distance between 20 and 30 m and between 500nT and about 1300nT at distance ranging between 40 and 60 m which

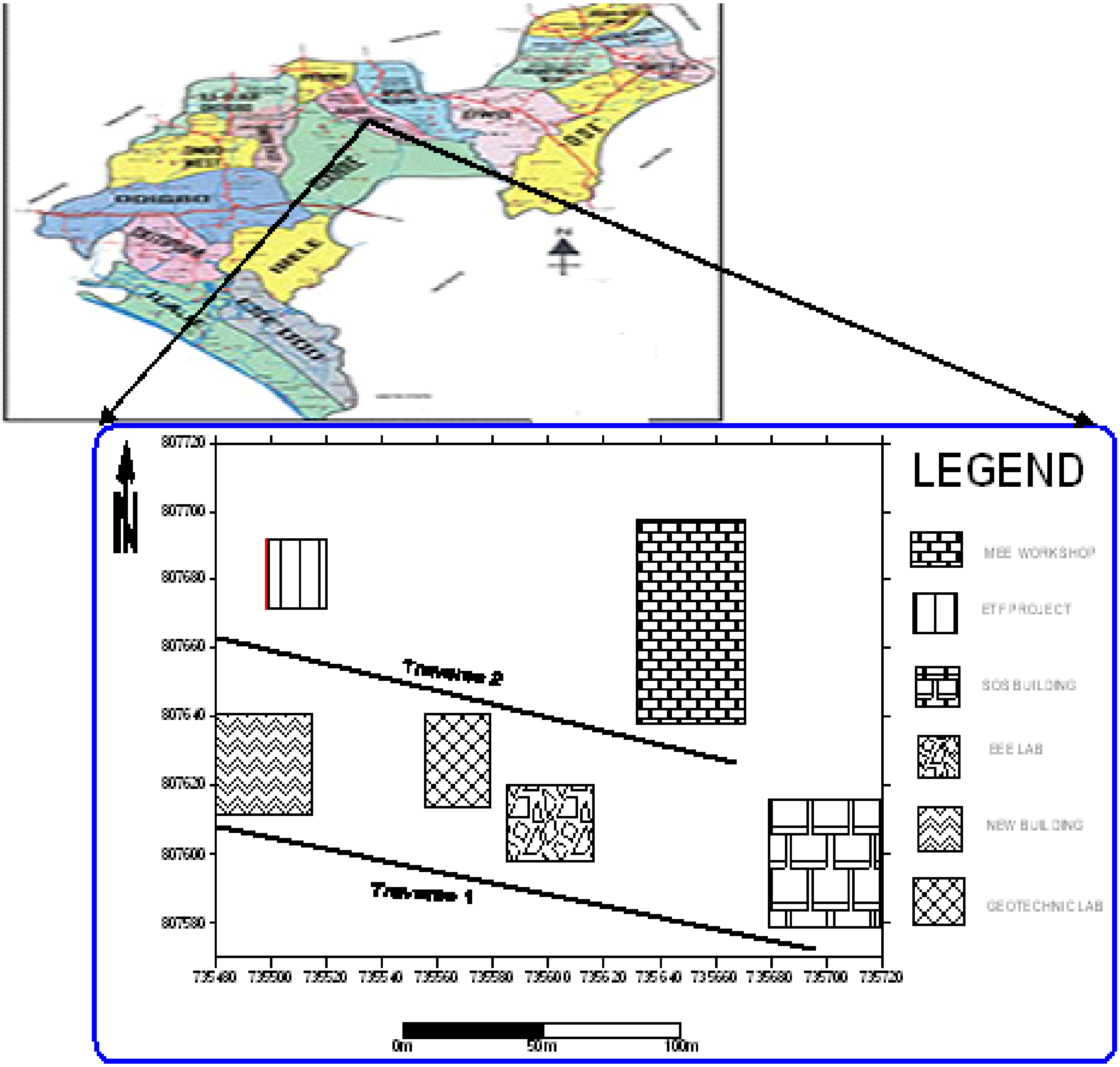


Figure 1. Location map of the study area.

are indicative of probable fracture zones. The automated Euler deconvolution software assist in the delineation of six probable fracture zones and estimated depth of between 5 m to about 20 m (Figure 4a). Continuous low magnetic intensity is observed at distance between 100 and 180 m which is typical of a fractured terrain although occurring at a greater depth. The magnetic intensity contrast along Traverse 2 observed between -2500 and -200nT at distance 30 to 50 m and between -50 and 500nT at distance 130 to 150 m are also indicative of probable fracture zones along the traverse. The Euler technique helps in delineating four probable fracture zones at depth of between 5 and 10 m (Figure 4b).

VLF-EM profiles

On Traverse 1, the VLF-EM profile identified peak positive filtered real values which corresponds to probable fracture zones at distances 20, 80, 110, 130 and 160 m. These observations agrees with the conductive zones delineated by the KH section at

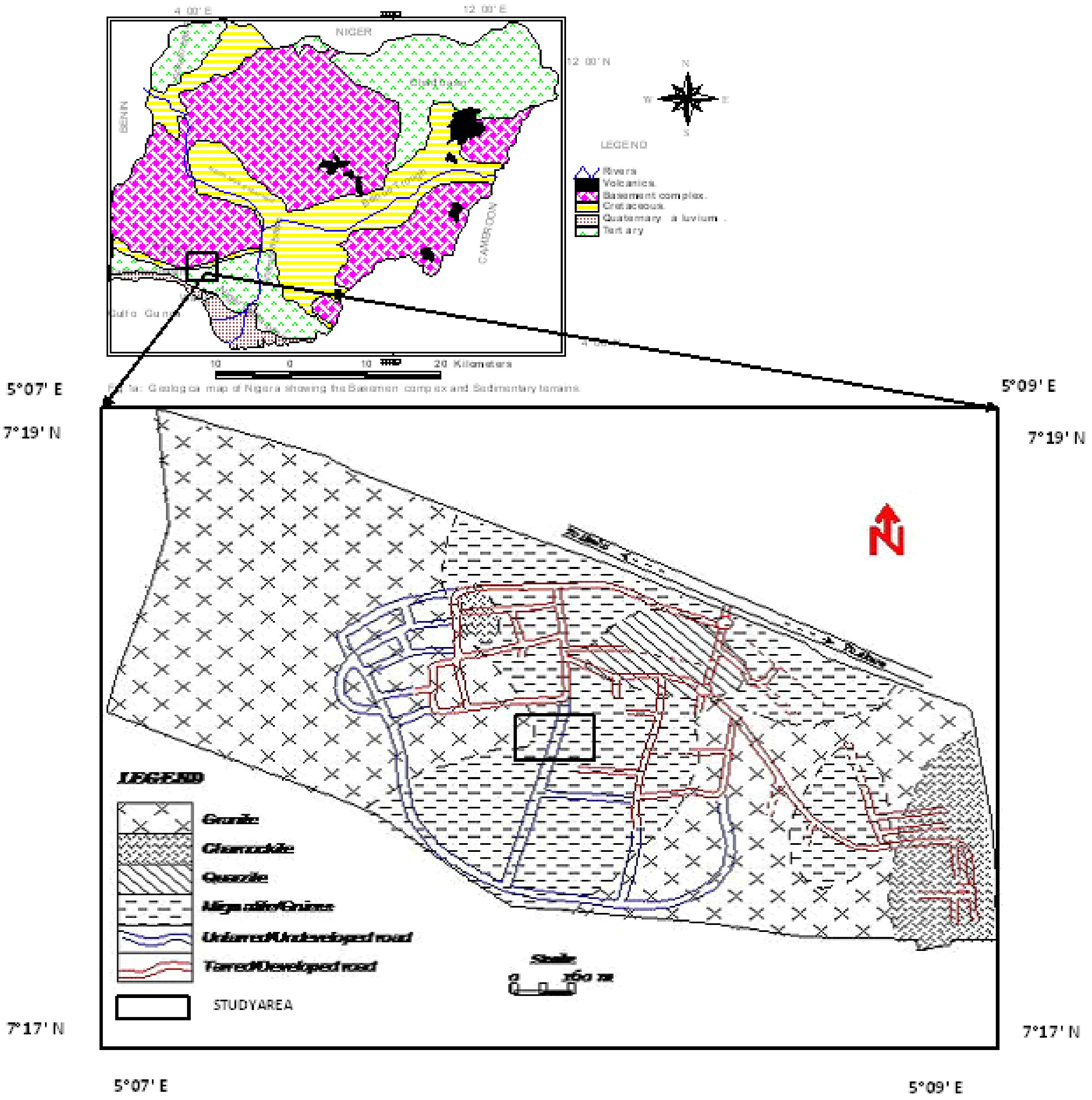


Figure 2. Geologic map of Nigeria top, geologic map of FUTA campus down (Modified after Kareem, 1995).

distances between 10 to 30 m, 60 to 80 m, 120 to 140 m and 160 to 180 m, respectively (Figure 5a). The conductive zone between 60 to 80 m is typical of a linear feature (fracture) because of its attitude that is dipping west. This agrees with the probable zone earlier delineated by the magnetic method at distance 40 to 60 m (Figure 5a). On Traverse 2, the VLF-EM profile identified peak positive filtered real values which correspond to probable fracture zones at distances 60 and 120 m. These coincides with the conductive zones delineated by the KH section at distances between 60 to 70 m at a very shallow depth and between 90 to 130 m which is typical of a linear feature and is dipping east (Figure 5b). The identified linear features have a significant depth extent. The identified linear feature coincides with a low magnetic intensity zone ranging between 60 and 120 m on the magnetic profile (Figure 4b).

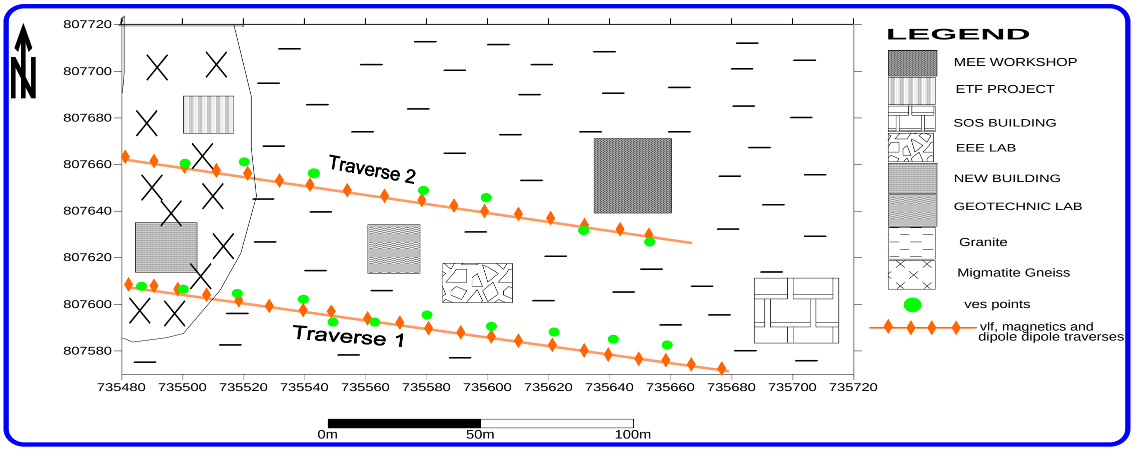


Figure 3. Data acquisition map of the study area.

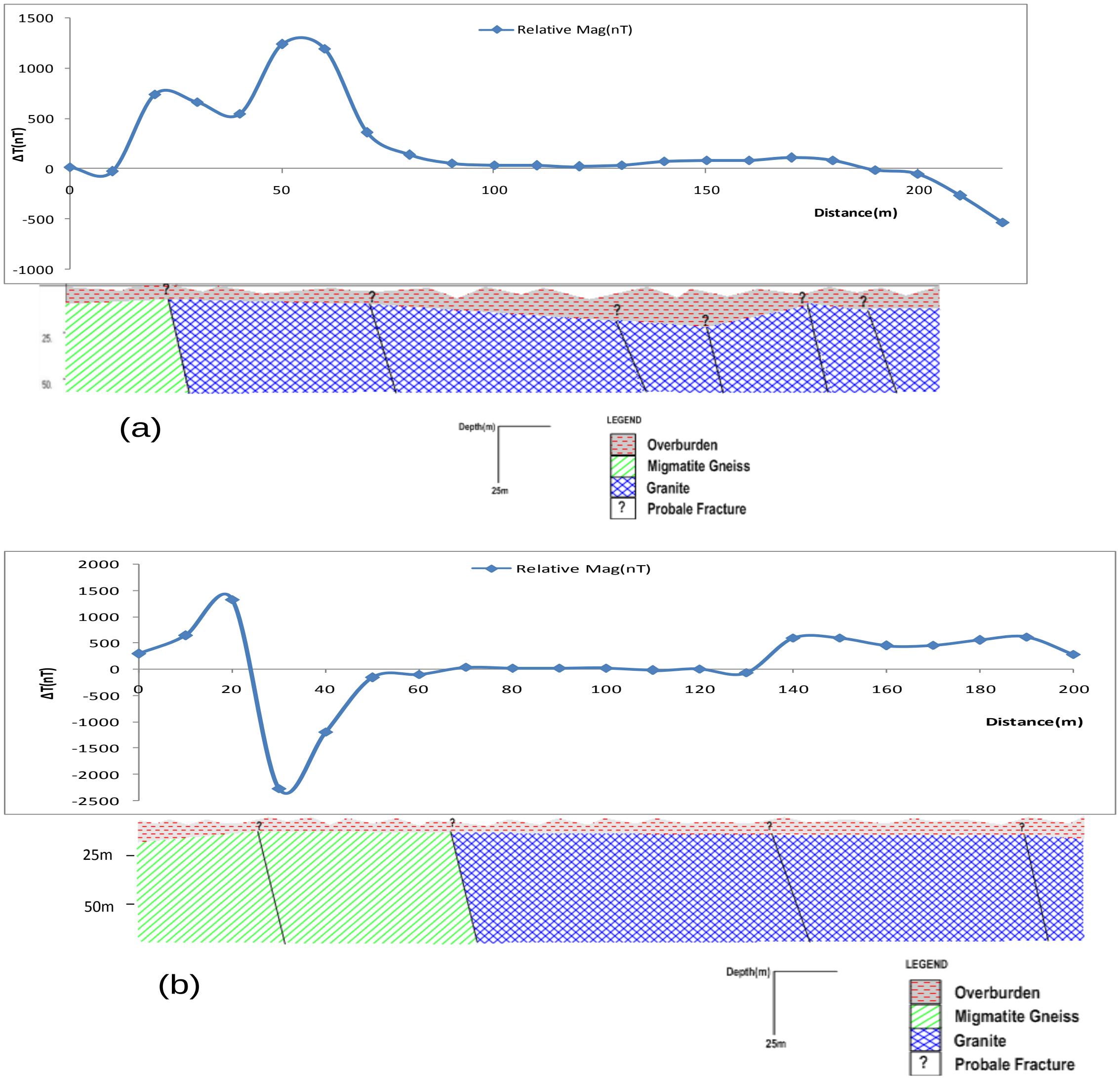


Figure 4. (a) Magnetic profile and its geomagnetic section along Traverse 1, (b) Magnetic profile and its geomagnetic section along Traverse 2.

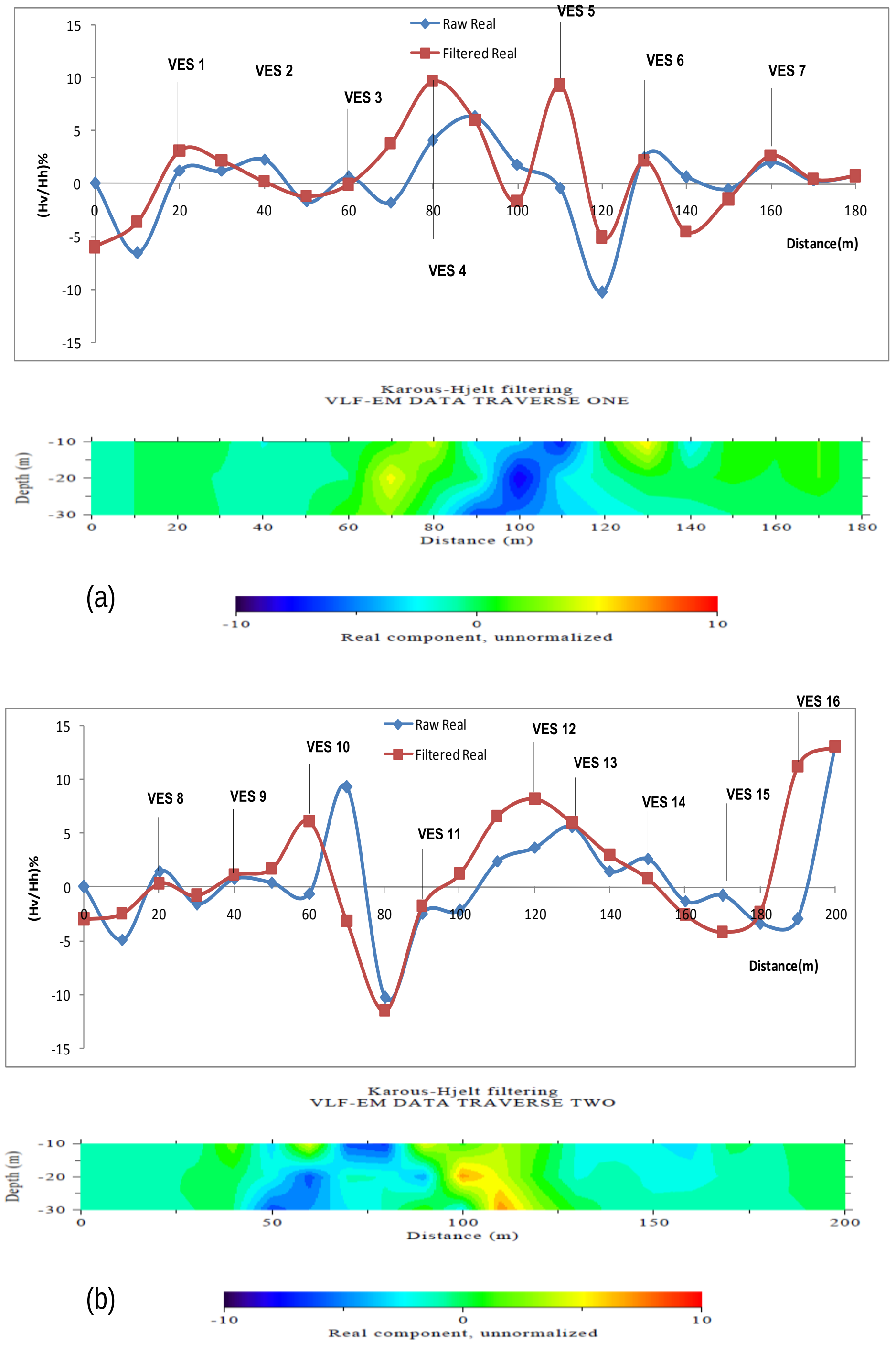


Figure 5. (a) VLF profile and KH Section along Traverse 1, (b) VLF profile and KH Section along Traverse 2.

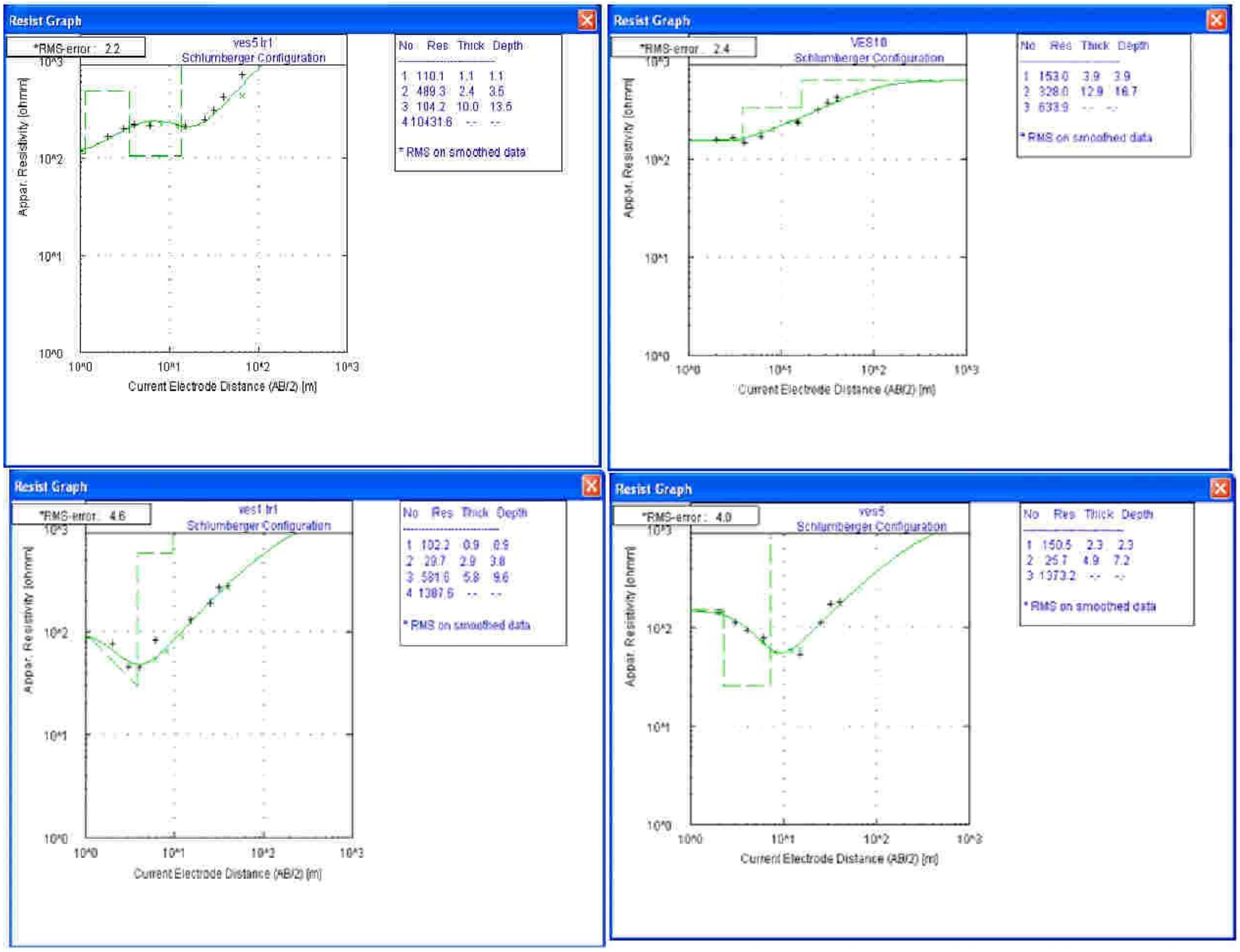
RESISTIVITY SOUNDING CURVES AND GEOELECTRIC SECTIONS

Characteristics of VES curves

Table 1 gives a summary of the interpretation results of the VES curves at each of the studied localities. The number of layers varies between 3 and 5. Five curve types have been identified in all the locations. These include the A, H, HA, KH, and QH type. Typical VES curves were presented in (Figure 6) with the KH and A curve type dominating with 38 and 31%, respectively.

Table 1. Summary of geo-electric parameters.

VES stations	Traverse lines	Thickness (m) $h_1/h_2/h_3$---/h_n	Resistivity (ohm-m) $\rho_1/\rho_2/\rho_3$/---ρ_n	Type curves
1	2	0.6/1.7/7.7	193/101/207/547	HA
2	2	0.9/2.2/7.5	169/320/72/3287	KH
3	2	2.7/22.1	47/174/1673	A
4	2	1.4/3.2/10.6	47/178/72/5738	KH
5	2	2.1/7.2	152/34/1846	H
6	2	1.2/2.9/7.9	80/122/30/543	KH
7	2	2.3/8.7	80/101/216	KH
8	1	0.9/2.9/5.8	102/30/582/1388	HA
9	1	0.7/1.9	65/13/394	H
10	1	3.9/12.9	153/528/634	A
11	1	3.0/5.4	395/723/95863	A
12	1	1.1/2.4/10.0	110/489/104/10432	KH
13	1	1.3/5.9/17.4	227/198/57/222	QH
14	1	0.6/2.2/7.9	63/284/38/1094	KH
15	1	1.6/3.0	33/186/2549	A
16	1	0.6/19.6	209/879/1220	A



No	Res	Thick	Depth
1	110.1	1.1	1.1
2	489.3	2.4	3.5
3	104.2	10.0	13.5
4	10431.6	--	--

* RMS on smoothed data

No	Res	Thick	Depth
1	153.0	3.9	3.9
2	328.0	12.9	16.7
3	633.9	--	--

* RMS on smoothed data

No	Res	Thick	Depth
1	102.2	0.9	0.9
2	29.7	2.9	3.8
3	581.6	5.8	9.6
4	1387.6	--	--

* RMS on smoothed data

No	Res	Thick	Depth
1	150.5	2.3	2.3
2	25.7	4.9	7.2
3	1373.2	--	--

* RMS on smoothed data

Figure 6. Typical VES curves from the study area (a=KH, b=A, c=HA, d=H).

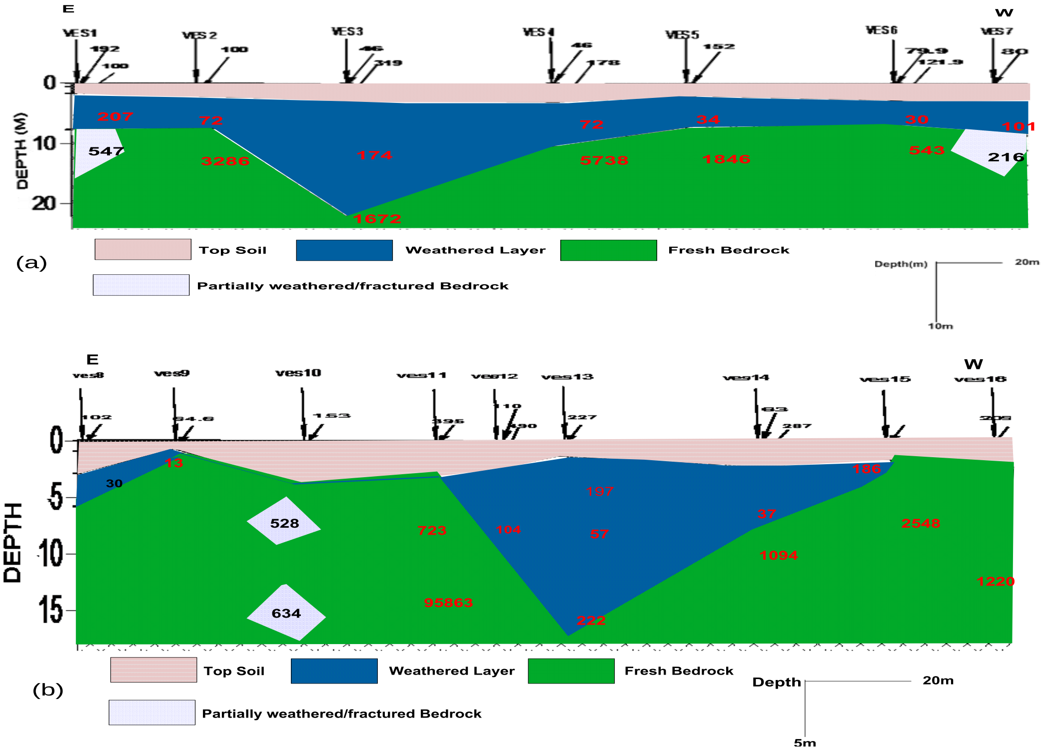


Figure 7. (a) Geo-electric section along Traverse 1, (b) Geo-electric Section along Traverse 2.

The HA and H curve type having 13% each and the QH curve type having 6%.

Geoelectric sections

The 2-D view of the geo-electric parameters (resistivity and depth) obtained from the inversion of the electrical resistivity sounding data are presented as geo-electric sections. The geo-electric section along Traverse 1 (Figure 7a) attempt to correlate the geo-electric sequence across the study area. Four subsurface geologic layers were delineated in the study area; the top soil, weathered layer, partly weathered/fractured basement and fresh bedrock. The topsoil (resistivity varies from 46.5 to 219 Ωm and thickness ranges from 0.6 to 2.7 m); weathered layer (resistivity varies from 72 to 207 Ωm and thickness ranges from 7.2 to 22.1 m), fractured bedrock (resistivity varies from 489.3 to 878.8 Ωm and thickness ranges from 2.4 to 19.6 m), bedrock resistivity (1139 to 5738 Ωm) and depth to bedrock (7.7 to 24.8 m).

On Traverse 2 (Figure 7b), four subsurface geologic layers were also delineated along this traverse. From the geo-electric section, the top soil, weathered layer, partly weathered/fractured basement and fresh bedrock were determined. The topsoil (resistivity varies from 63.5 to 490 Ωm and thickness ranges from 0.6 to 3.9 m); weathered layer (resistivity varies from 13 to 197 Ωm and thickness ranges from 1.9 to 17.2 m, fractured bedrock (resistivity varies from 489.3 to 878.8 Ωm and thickness ranges from 2.4 to 19.6 m), bedrock resistivity (1094 to 96583 Ωm) depth to bedrock (2.6 to 19.5 m).

Dipole-dipole Pseudosections

The 2-D Pseudosection was produced from the dipole-dipole data taken along the two traverses (Figure 8a, b). It was set up to have a 2-Dimensional clear view of the subsurface because it shows an interpretation of unilateral data and its contours. This also gave similar information as the geo-electric section. It delineated topsoil, weathered/fractured layer (thickness 8 to 20 m) and the fresh bedrock. The resistive parts are seen at the lower part of the section which is the fresh bedrock while the green and blue coloured parts are the fractured part of the section. A suspected linear feature was delineated at distance 60 to 100 m (Figure 8a).

The 2-D pseudo-section was also produced from the dipole-dipole data taken along Traverse 2 (Figure 8b). This also gives similar information as the geo-electric section. It delineated topsoil, weathered/fractured layer and the fresh bedrock. The highly resistive parts are seen at the lower part of the section which is the fresh bedrock while the green and blue coloured parts are the weathered/fractured part of the section. A suspected

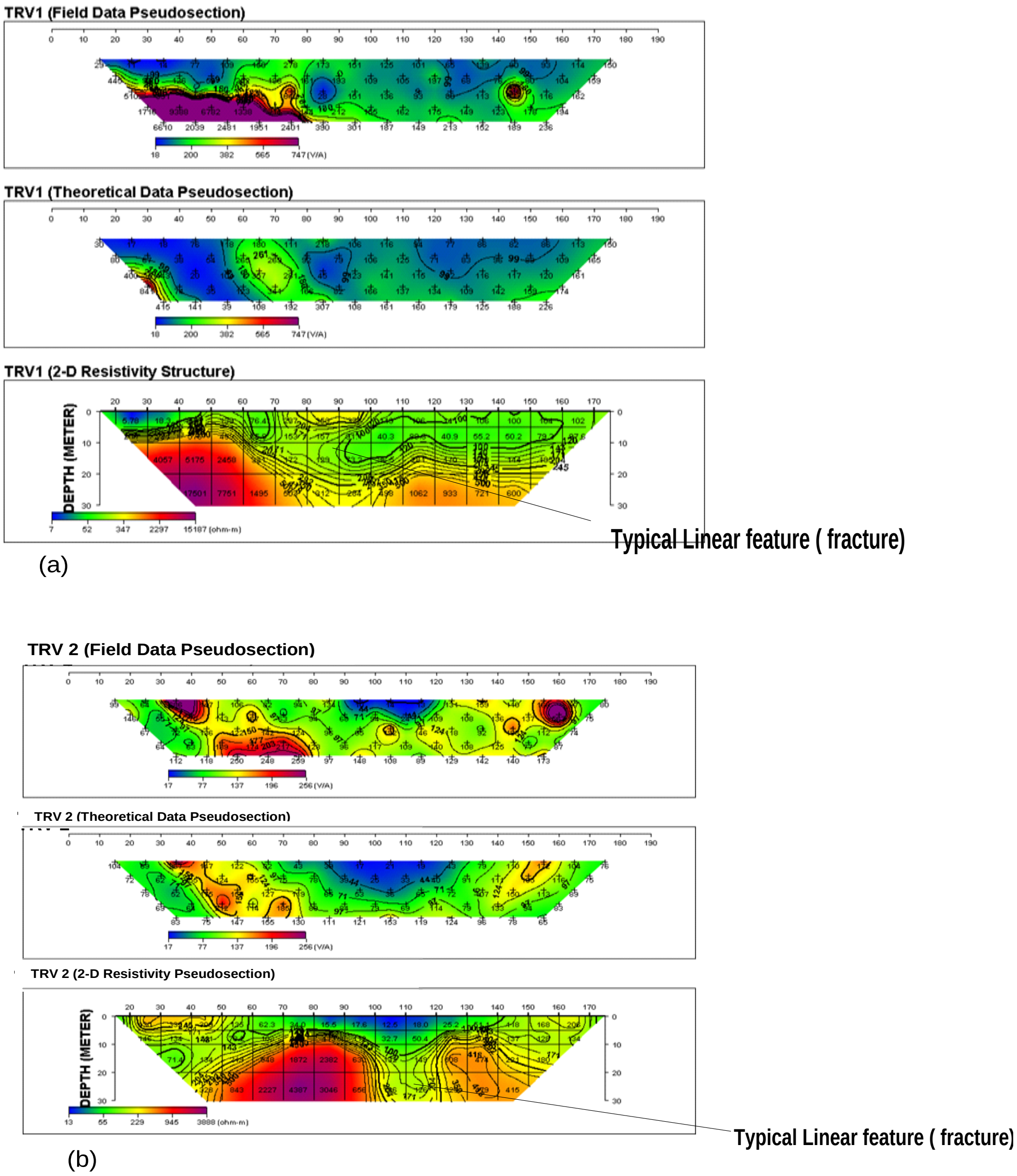


Figure 8. (a) Dipole -dipole pseudosection along Traverse 1, (b) Dipole -dipole pseudosection along Traverse 2.

linear feature was delineated at distance 100 to 120 m along Traverse 2 (Figure 8b).

ISORESISTIVITY AND ISOPACH MAPS

Isoresistivity map of topsoil

Figure 9a shows the isoresistivity map of the topsoil. The topsoil comprises of sandy clay/clayey sand formation with resistivity values ranging from 40 to 380 Ωm. The highest resistivity values were identified towards the South western flank of the study area up to 380 Ωm which may be suitable for foundation works if the thickness is considerable. The lowest resistivity values were identified at the Northern, western, and southeastern region (40 Ωm) which is not suitable for foundation works.

Isopach map of topsoil

Figure 9b shows the Isopach map of the top soil. The map shows the largest thickness at the Southeastern

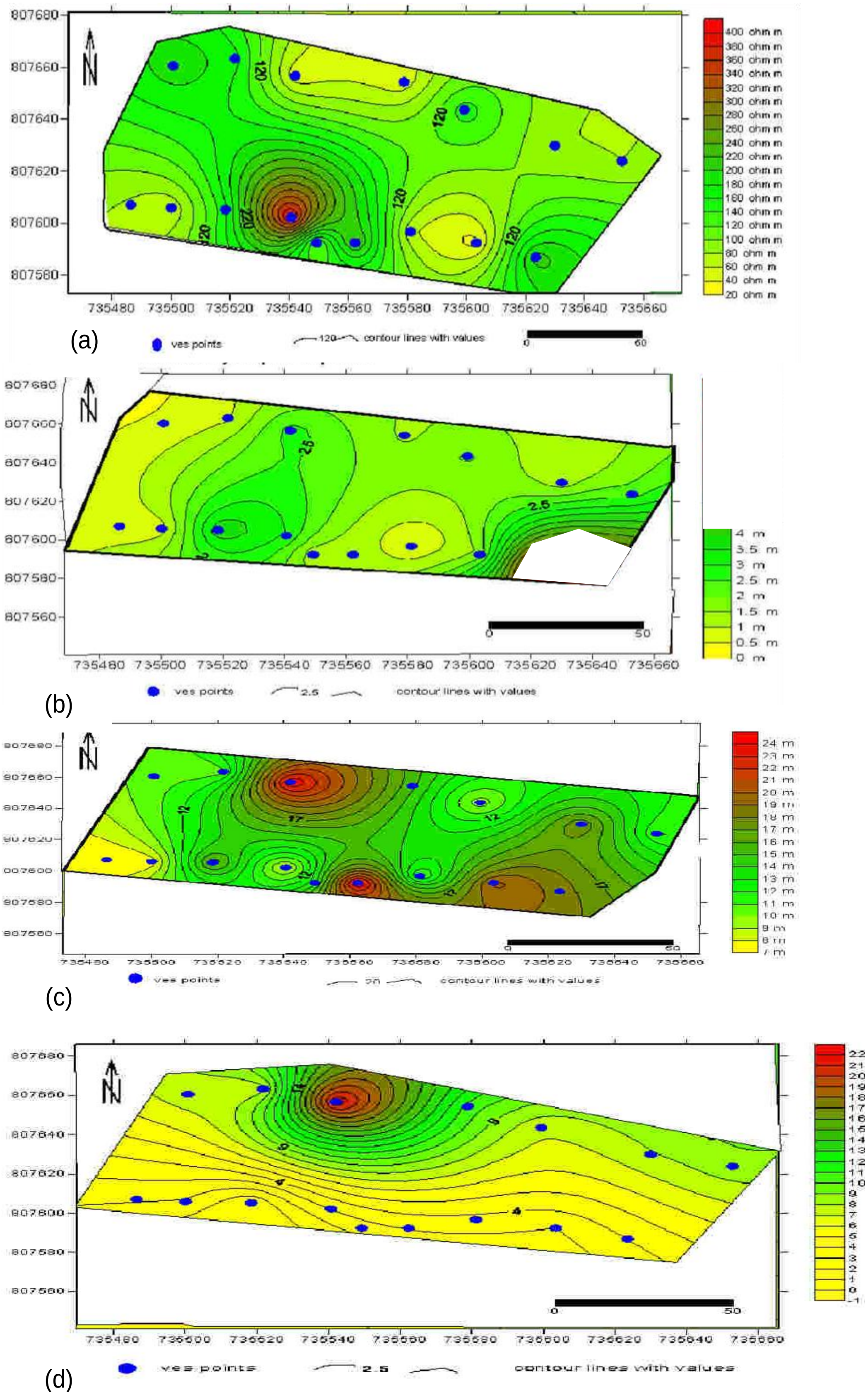
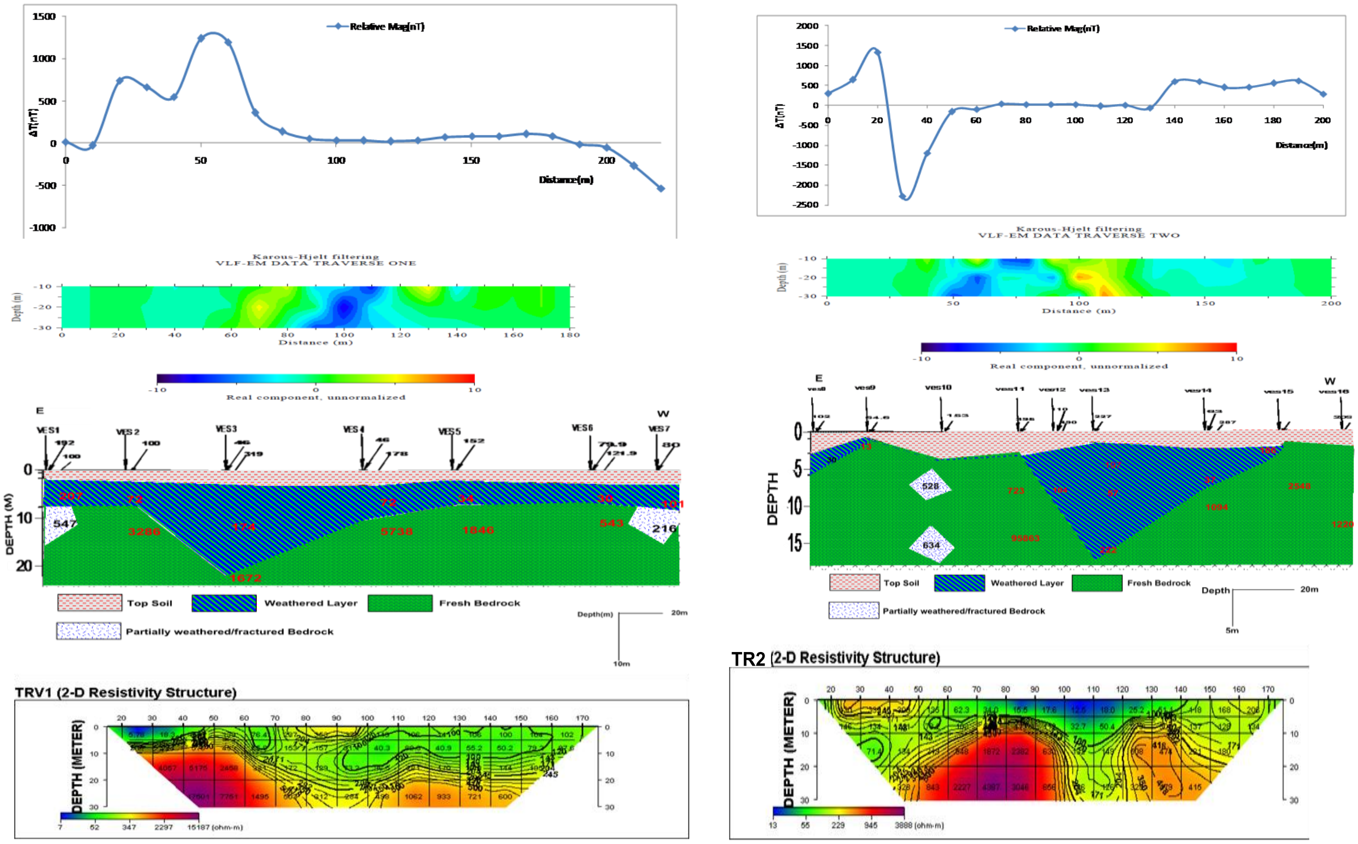


Figure 9. (a) Isoresictivity mapof top soil, (b) Isopach map of top soil, (c) Isopach map of overburden, (d) Isopach map of weathered layer.



(a) (b)

Figure 10. (a) Summary of results along Traverse 1 showing the magnetic profile, VLF-EM section, geo-electric section and dipole-dipole pseudosection, (b) Summary of results along Traverse 2 showing the magnetic profile, VLF-EM section, geo-electric section and dipole-dipole pseudosection.

flank of the study area with thickness of about 3.9 m. The lowest thickness values were identified towards the Northwestern flank of the study area up to 0.6 m.

Isopach map of overburden

Figure 9c shows the isopach map of the overburden. The overburden consists of two formation topsoil and the weathered layer. The southern parts of the area have the highest thickness value at the Northwestern and Southwestern flank of the study area with thickness of about 24 m. The lowest thickness values were identified towards the Western flank of the study area.

RESULTS

Figure (10a) shows the summary of profiles and sections obtained from various geophysical methods employed along Traverse 1. The magnetic intensity contrast observed at distance 20 to 30 m coincides with the conductive zones delineated by the VLF-EM section at distance 10 to 30 m. This also agree with the low resistivity zone (fracture zone) observed on the dipole-dipole pseudo-section at distance between 20 and 40 m at depth 0 to 8 m. The linear feature delineated on the dipole-dipole pseudo-section at distance 60 to 100 m (Figure 8a) coincides with depression observed on the geo-electric section at distance between 80 to 140 m and is also delineated as conductive zones by the VLF-EM section at distance 60 to 80 m. These results reveal that the geophysical methods used for this study are complimentary.

Figure (10b) shows a magnetically quiet environment at distance ranging from 60 to 120 m. There might be existence of structures very close to the surface at this point since the VLF section was able to identify conductive zone at the distance which also agrees with low resistivity zone observed on the 2-D resistivity structure. The delineated linear feature (fracture) observed on the 2-D image occurring between

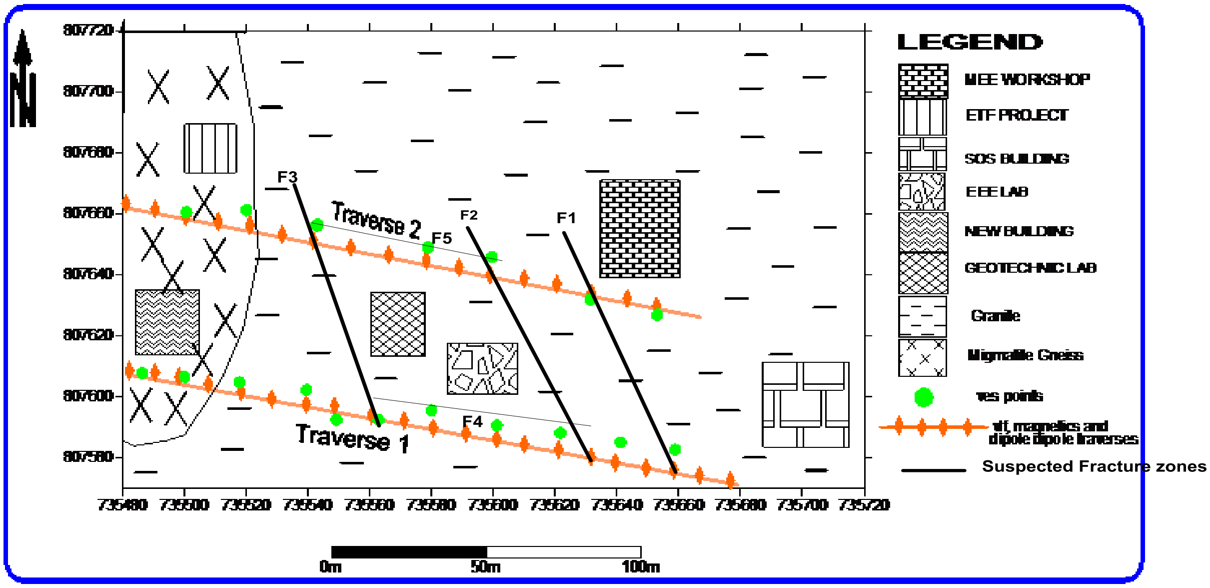


Figure 11. Structural map of the area.

100 and 120 m is also revealed on the VLF-EM section as a linear feature at distance 90 to 130 m.

Structural map of the area

The structural map developed from the VLF-EM, ground magnetic and dipole-dipole results are presented in Figure 11. Five fracture zones designated F_1 to F_5 were delineated. The ground magnetic combined with the VLF-EM method assist in delineating vertical discontinuities F_1, F_2 and F_3 while the 2-D resistivity image of the sub surface identified continuous near surface fracture zones at distance 60 to 170 m and 60 to 140 m on Traverse 1 and two, respectively. These fractures are designated F_4 and F_5 along Traverse 1 and 2, respectively. These structures suspected to be a major faulted zone underlies the study area especially the electrical electronics engineering (EEE) and Geotechnical lab. The presence of these structures poses danger to the continuous existence of the structures erected in this location.

Conclusion

In conclusion, the Geophysical methods were successful for post construction studies. The interpretation of VES, VLF–EM, magnetic and the dipole-dipole pseudo-section in the study area have allowed the delineation of incompetent zones in the study area. Five fracture zones designated as F_1 to F_5 believed to be a major faulted zone underlies the buildings in the study area with the 2-D image of the subsurface identifying near surface fractures that are inimical to engineering works. This shows that subsurface geologic setting underlying the buildings is inhomogeneous and therefore can be said to be structurally deformed. The identified weak zones expose the buildings to future failure and eventual collapse. Based on the geophysical investigation, the competence of the subsurface of the study area can be generally classified as incompetent. Three major causes of potential failure in the area were also identified, these are; failure due to lateral inhomogeneity of the subsurface layers, failure precipitated by differential settlement and failure initiated by geologic features such as fractures and faults. Subsequent construction in the area should be founded on the fresh basement layer coupled with pile foundation to ensure the stability of the building.

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