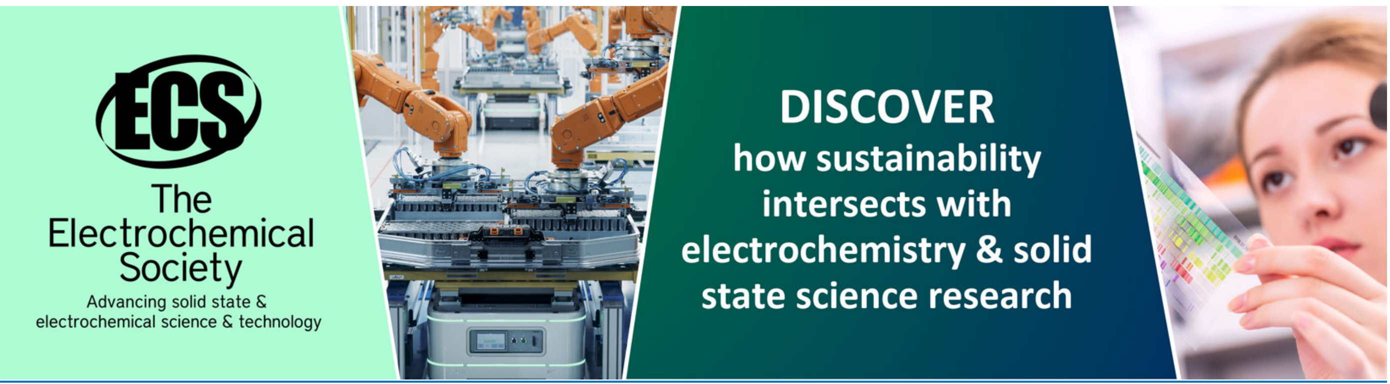
IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Investigation into the types of fracture and viable depth to substratum of a housing estate using geophysical techniques

To cite this article: T.A. Adagunodo *et al* 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **173** 012030



Investigation into the types of fracture and viable depth to substratum of a housing estate using geophysical techniques

T.A. Adagunodo[1], L.A. Sunmonu[2], A.V. Erinle[2], M.A. Adabanija[3], K.D. Oyeyemi[1], O.T. Kayode[1]

[1]Department of Physics, Covenant University, Ota, Nigeria
[2]Department of Pure and Applied Physics, Ladoke Akintola University of Technology, Ogbomoso, Nigeria
[3]Department of Earth Sciences, Ladoke Akintola University of Technology, Ogbomoso, Nigeria

taadagunodo@yahoo.com; erinleayo@yahoo.com; taadagunodo@gmail.com

Abstract. Mapping of the configuration of bedrock is paramount in civil engineering and hydrogeological settings. In civil engineering, areas that are extensively fractured (either shallow or deep) are adjudged as weak zones whereby these provinces are regarded as copious zones for groundwater exploration. Very Low Frequency Electromagnetic (VLF-EM) and ground magnetic survey were carried out in Olupona Housing Estate along seven traverses with interstation spacing of 20 m. For the two methods, traverses 1 to 3 were taken in North-South azimuth which covered distance 300 m while traverses 4 to 7 were acquired along East-West azimuth which covered distance 400 m. VLF-EM results revealed Type-1 fracture along traverse 1, traverses 2 to 4 showed no fracture but a fairly competent bedrock. Type-2 fractures were revealed on traverses 5 to 7 while Type-3 fracture was shown on traverse 5 alone. Ground magnetic results depicted that the depths to biotite or biotite muscovite granite are relatively deep. The mineral rocks with very thin, intermediate, and very thick bodies have their depths range as 14.7 m, 11.0 m and 8.8 m respectively. On the average, the depths to these mineral rocks from the surface varied from 6.5 to 19.6 m. The trends of the identified fractured zones are NE-SW and NW-SE directions. It is concluded that in order to avoid building collapse in future, construction of high-rise buildings is unadvisable in the study area. If the identified fractured zones are properly maximized for groundwater exploration, the fractured zones can be optimized such that reservoir(s) can be constructed so as to supply water to the houses for domestic usage.

Keywords: Fracture distribution; weak zones; ground magnetic; overburden estimates; VLF-EM.

1. Introduction

Fracture in basement terrain is a break in crystalline basement rock as a result of tectonic forces or magma intrusions into the parent rock [1]. Determining its distribution and type for hydrogeological and civil engineering purposes is paramount. Its identification in civil engineering study helps to establish the precise foundation type and appropriate depth to which the foundation of a building must be laid. In civil engineering study, areas with deeper and wider fracture are considered as weak zones. These zones would be interpreted as the promising zones for groundwater exploration. In hard rock terrain, groundwater yield is greatly dependant on the size of fracture and its interconnectivity because it is located in fractures and cracks of the local rock. However, slightly fractured and shallow fractured zones are still considered as competent zones for civil engineering purposes but the users need to seek expert's advice before any structures would be erected [1].

Geophysical methods had been proven as the economical complement to expensive drilling of test wells in fluid studies and to determine the location and orientation of fractured zones in the subsurface. They can be integrated with geologic, borehole and hydrogeological techniques to enhance well sitting or as 'stand alone' method for fracture detection. In some situations, buildings that are expected to be an abode of peace to the people have become sources of great concern to the owners and occupiers as a result of the persistent failure in these structures [2]. This is what happens when the geophysical methods (especially a pre-foundation study) that map the subsurface systems are neglected.

The developments of human beings have solely been dependent on subsurface resources, either those obtained from near surface/shallow depth (for civil engineering purposes) or those obtained from deeper depth (for mineral exploration or crude oil). Today, good source of water for domestic and industrial purposes also come from the subsurface aquifers, structures that interface safely with these shallow regions are built and human wastes are being deposited also to this subsurface [3].

In conjunction with all these factors, subsurface characteristics that attract geoscientists include location, distribution, structure and depth of rock types, porosity, permeability, strength and grain size distribution of rocks in the subsurface etc. The earth's intrinsic intricacy could make it unfeasible to deduce these attributes through direct observation. As a result of this, they are often inferred through the fundamental physical properties such as electrical conductivity, density, acoustic impedance and magnetic susceptibility [4].

Ground magnetic study is used to map a localized zone in order to understand and interpret its geology. Ground magnetic technique entails measuring the magnetic components' amplitude at discrete point along the distributed traverses that would cover the entire survey area. In ground magnetic method, the three (3) components being measured are vertical, horizontal and total components. One or two of these components have been used to map out fractures, faults, magnetic basement's depth, and other geological features. The magnetic method has been found useful in location of buried magnetite ore bodies due to its high magnetic susceptibility [3, 5].

It is more efficient to use VLF-EM method in the near surface fracture delineation than estimation of overburden thickness, because their anomalies are influenced by the overburden's conductivity than the thickness [6]. VLF-EM method exhibits very high penetration depth in crystalline (hard rock) terrain due to its high resistivity. VLF is capable to delineate fractures in lateral direction effectively compared to electrical resistivity sounding and to also characterize aquifer structures in a complex region [1].

This study is aimed to determine the fracture type in the study area which would be useful for civil engineering purposes and perhaps groundwater exploration. The outcome of this study shall complement the previous study carried out by Sunmonu *et al.* [7] in the study area in order to affirm the type of buildings to erect on the site and possible locations for groundwater exploration. In this study, VLF-EM and ground magnetic techniques were espoused. VLF-EM was considered because it is the best technique for reconnaissance survey that is capable to map geological structures while ground magnetic approach was utilized to map the magnetic anomalies in the subsurface.

Responses of VLF-EM method to subsurface variations have been studied by Paal [8], Babu *et al*. [9], Gnaneshwar *et al*. [10], Adagunodo *et al*. [11] and Olafisoye *et al*. [12]. Magnetic applications have been extensively researched on by Adagunodo and Sunmonu [13], Adagunodo *et al*. [14], [15] and Sunmonu et al. [16]. However, integration of VLF-EM and ground magnetic methods have been used by Ogungbemi and Oladapo [6] to investigate on the hydrogeophysical characterization of Ijapo Housing Estate, Akure and Babu *et al*. [9] to map basement fractures in Raigarh, India. However, other geophysical techniques have been found applicable in the interpretation of subsurface structures. Few of these techniques can be found in Refs. [17-25].

2. Geographical and geological settings of the study area

The study area is the proposed location for Olupona Housing Estate which falls within Latitude 07° 6.4430' – 07° 6.6600' north and Longitude 04° 2.0017' – 04° 2.1733' along Iwo–Ibadan road, Osun state, southwestern Nigeria. Accessibility of the study area is through major and minor road networks that link Housing Estate with Olupona village. The area under investigation belongs to the tropical rainforest region, which is experienced in most of southwest, Nigeria. There are two distinct seasons in the study area; the wet and the dry seasons. Wet season occurs between the months of March through October while dry season runs from November through February. These two seasons define the climate of the area under investigation [7].

The study area is underlain by the Precambrian to Cambrian basement Complex of Osun state, southwestern Nigeria which is subdivided into Pan African (Older) Granitoids, metasediments/metavolcanic series, and migmatite gneiss complex. Olupona, falls within Pan African (Older) Granitoids with biotite and biotite muscovite granite being the major rock groups in the vicinity the study (Fig. 1).

3. Materials and Method

ABEM-WADI, a VLF equipment was employed fro EM data acquisition while the magnetic technique employed Proton Precision Magnetometer for its data acquisition. Seven (7) traverses were occupied for VLF-EM survey with inter-station spacing of 20 m. Ground magnetic data were acquired on the same traverse as that of VLF-EM employing the same inter-station spacing. Traverses 1 to 3 were taken in North-South azimuth which covered the total length of 300 m while traverses 4 to 7 were acquired in the East-West azimuth which covered the total length of 400 m.

The theory and application that governs VLF-EM has been reported by several authors, among these researchers are Babu *et al*. [9], Gnaneshwar *et al*. [10] and Adagunodo *et al*. [11]. As reported by Gnaneshwar *et al*. [10] that, VLF-EM is one of the existing passive methods which operates on the 'Principle of EM Induction'. This technique utilizes radiation from radio transmitter (Tx), a military-based Tx at about forty-two (42) locations globally which are employed for navigation. The Tx operates within primary EM field varying from 15 to 30 kHz. These radio transmitters produce plane EM waves that could induce secondary eddy currents, particularly in electrically conductive elongated two-dimensional targets. Despite the range of frequency generated is very low for radio transmission, it is still higher than those used in standard low-frequency electromagnetic methods (1 to 3 kHz). Paal [8] observed that radio waves at very low frequencies could be used to prospect for conductive mineral deposits. Following this breakthrough, the world very low frequency transmitters have been found useful globally as electromagnetic sources for near-surface geologic mapping Babu *et al.* [9]. As Gnaneshwar *et al*. [10] have reported, "very low frequency method generally yields considerable electromagnetic anomalies, even over poor conductors such as sheared contacts, fracture zones, and faults". Therefore, this method has been so favoured and become a very renowned tool for the swift mapping of the geological structures in near-surface.

VLF-EM data were processed by downloading the filtered real and imaginary components from the Abem Wadi VLF-EM equipment. WADI VLF-EM detects the ratio (in percentage) between the vertical and the horizontal components, which is indicative of the degree of in homogeneity of the subsurface. This instrument measures the field strength and the phase displacement around the fracture zone. The filtered real and the filtered imaginary data were plotted against the station separations in order to determine the fracture types in the study area. Ground magnetic data were drift corrected. The residual data were further enhanced using Total Horizontal Derivative.

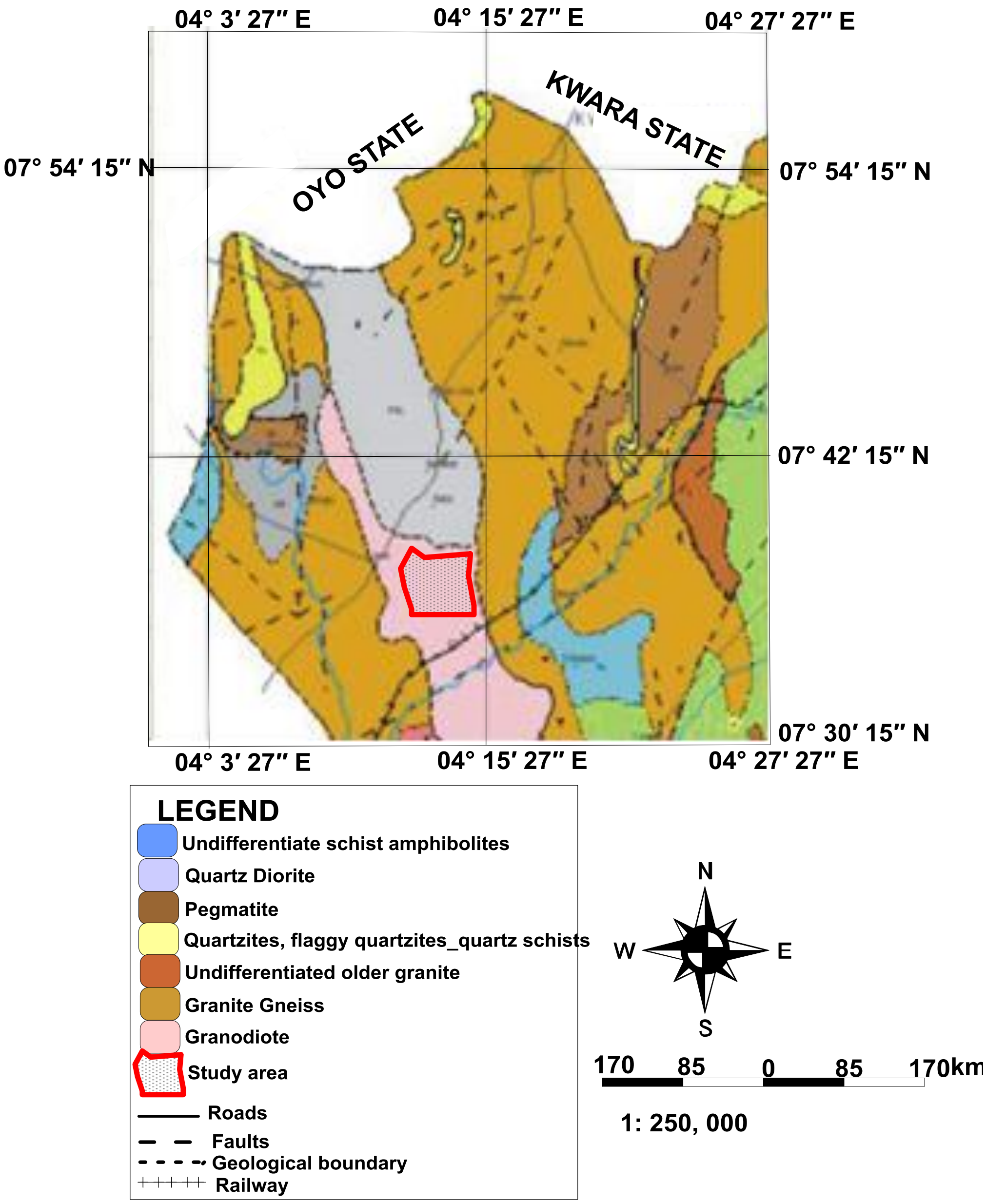


Fig. 1. The Geological domains in some parts of Osun State showing the study area

Total derivative is the maximum gradient of the magnetization. One of the applications of magnetic data to geological interpretation is the delineation of the magnetized structures' edges. Vertical and horizontal derivatives are regularly employed to intensity the magnetic data's details. The total horizontal derivative and analytic signal are two effective tools that are used to detect the edges of magnetized structures [26]. A commonly used edge detection filter is the Total Horizontal Derivative (THDR) and it is given by Cordell and Grauch [27] as:

$$\text{THDR} = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2} \qquad (1)$$

where T is the magnetic field, $\frac{\partial T}{\partial x}$ and $\frac{\partial T}{\partial y}$ are the two orthogonal horizontal derivatives of the magnetic field. The advantage of using THDR over other enhancement techniques is that it is more effective when imaging for shallower bodies than that of the deeper bodies [26].

The enhanced data was finally presented as map and profiles of relative magnetic intensity values against station separations. Surfer 11 Software was used to process the 2-D map of the study area. However, the overburden thicknesses of the study area were determined using Peter-half slope method [28]. The method has recently been used by Ojo *et al*. [3]. However, the integration of VLF-EM and ground magnetic techniques used in Olupona Housing Estate enabled the subsurface characterization for fracture type mapping and depth to bedrock estimates. This characterization would be essential for civil engineering and hydrogeological purposes in the study area. Automated Euler deconvolution software was used to juxtapose the linear features that have been revealed through other techniques. This was done in order to enhance the production of geomagnetic section of the study area. Geomagnetic sections of the study area were presented along seven profiles. These were deduced from the weighted average of the results from the geology and the integrated geophysical techniques used in the study area. The map, profiles and sections generated were used to conclude on the concealed geological structures in the study area.

4. Results and Discussion

4.1. VLF-EM results

The results of VLF-EM are presented as field plot for all the seven traverses (Figs. 2a to 2g). In Fig. 2a, the filtered real and imaginary were in-phase with filtered real having higher amplitude compared to filtered imaginary that is closer to zero. This indicates the material contents in fracture zone are of high resistivity suggesting fresh water. Furthermore, the symmetry of filtered real and imaginary suggests the fractured zone is directly beneath 300 m that is non-dipping. Therefore, Type-1 fracture (single fractured zone at 300 m without overburden) is experienced towards the end of traverse 1. Thus, the point is favourable for groundwater prospecting but the absence of overburden may be a draw-back. However, the location is not suitable for civil engineering purposes.

Type-2 fracture (another form of fracture) occurred at horizontal distance of about 60 m along profile 5 (Fig. 2e). Type-2 fracture was also observed at horizontal distance of about 145 m along profile 6 (Fig. 2f); and about 20 m and 175 m along profile 7 (Fig. 2g). However, the fractures are dipping (not directly or vertically beneath the points of observations) as exemplified by asymmetry of the peaks of their amplitudes. Directional drilling will be required to explore such fractures successfully. At horizontal distance of about 245 m along profile 5 (Fig. 2e), there was a double fractured zone with overburden (Type-3 fracture) as exemplified by behaviour of both filtered real and filtered imaginary such that when the field passes through the overburden, the amplitude of filtered imaginary is reduced and its phase somewhat displaced. The presence of overburden is evidence of weathering suggesting double fracture zone with overburden and has a better prospect for groundwater exploration compared to single fracture without overburden.

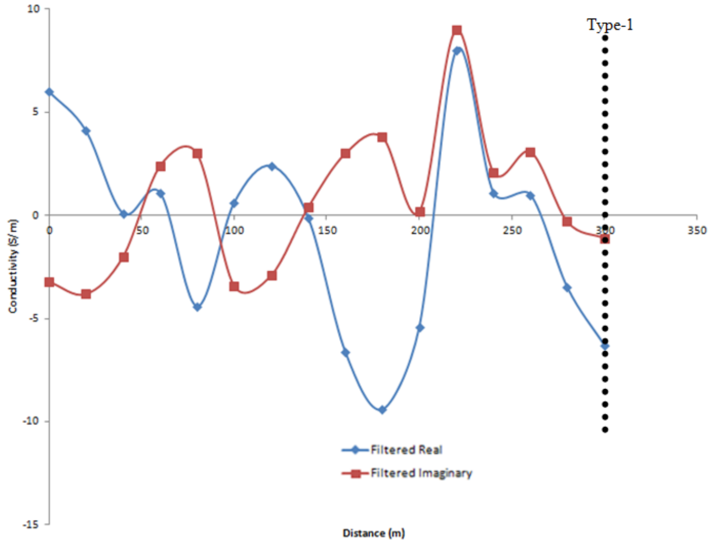


Fig. 2a. The VLF-EM plot of Traverse 1 (from north to south)

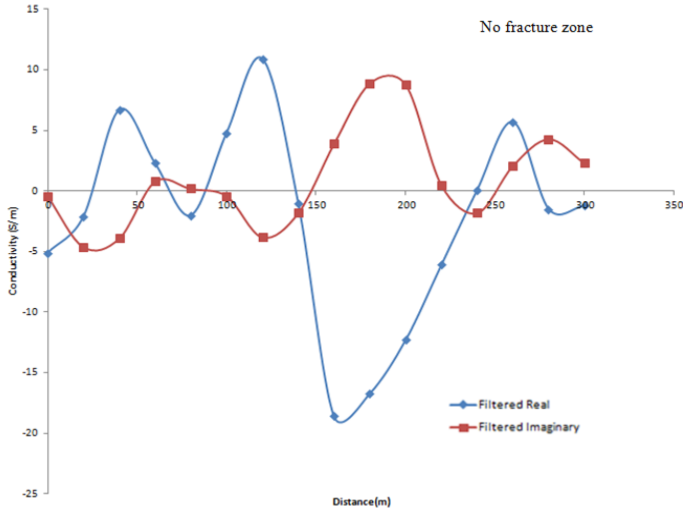


Fig. 2b. The VLF-EM plot of Traverse 2 (from north to south)

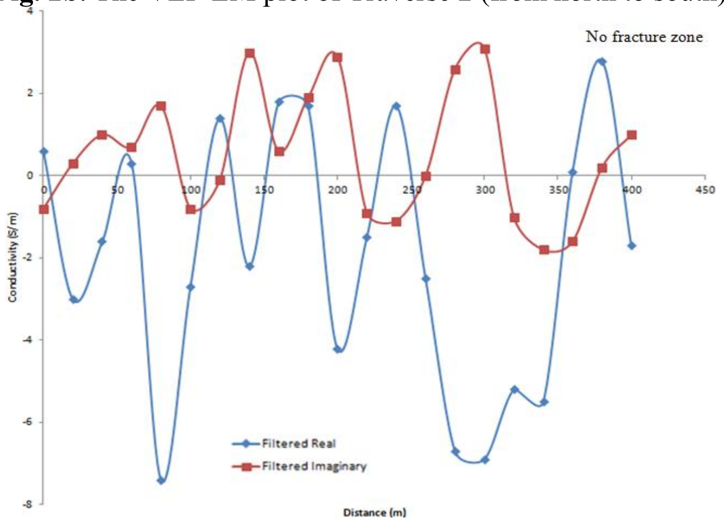


Fig. 2c. The VLF-EM plot of Traverse 3 (from north to south)

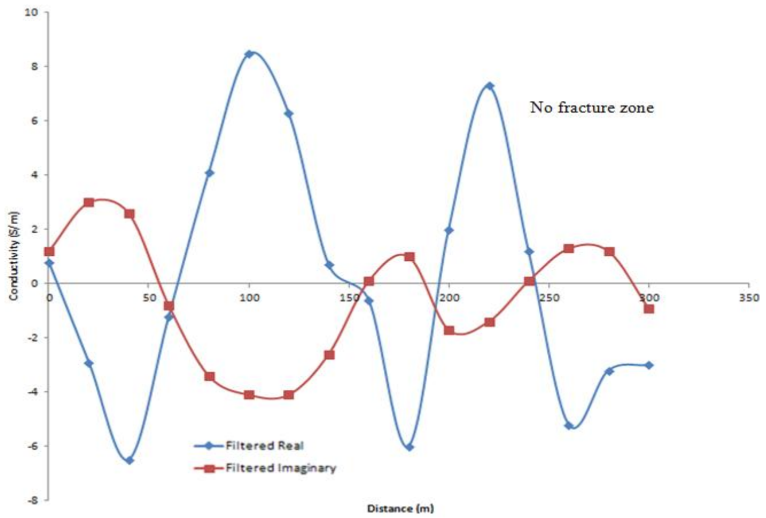


Fig. 2d. The VLF-EM plot of Traverse 4 (from east to west)

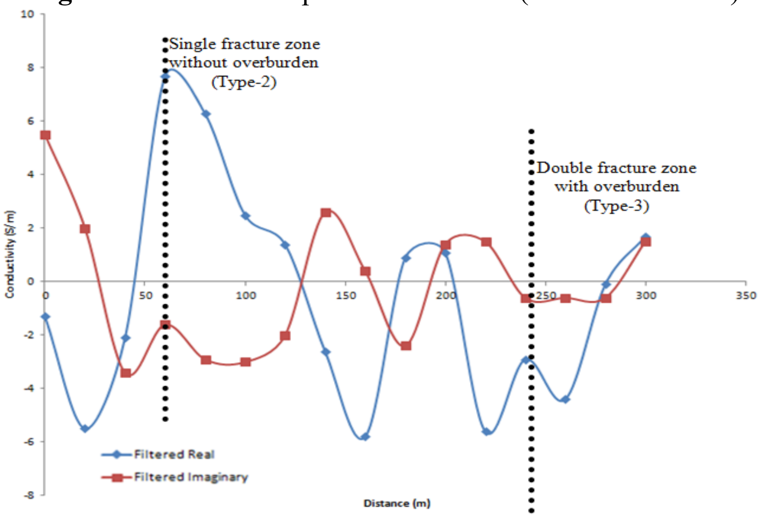


Fig. 2e. The VLF-EM plot of Traverse 5 (from east to west)

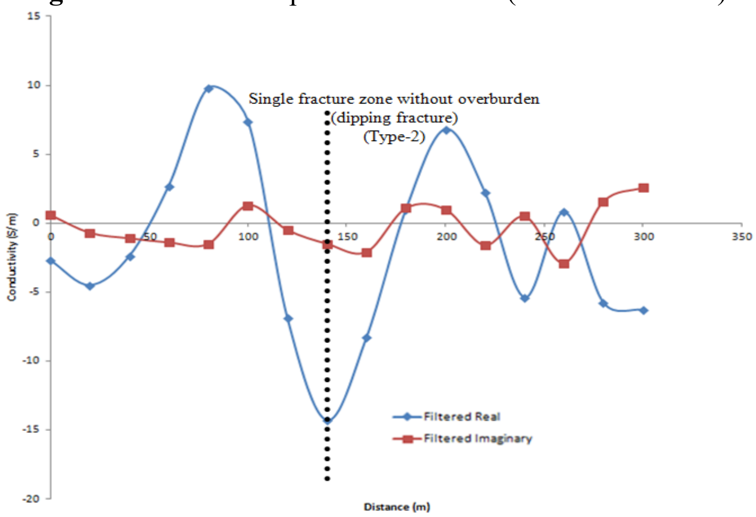


Fig. 2f. The VLF-EM plot of Traverse 6 (from east to west)

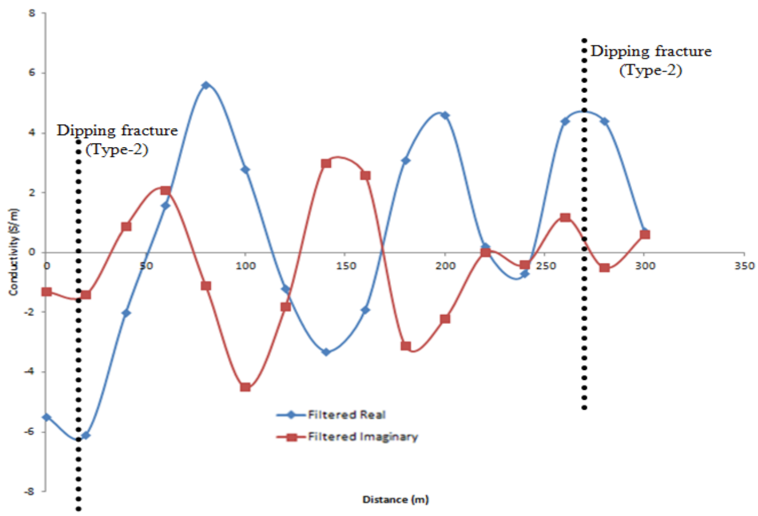


Fig. 2g. The VLF-EM plot of Traverse 7 (from east to west)

Along traverse 4 (Fig. 2d) four distinct zones of positive peaks (high conductivity) were observed on this model. The filtered real and the filtered imaginary are out of phase all through suggesting the zone is resistive, which is an indication of competent zone for civil engineering activities. It is evident from the model section that the subsurface beneath this traverse is fairly competent. The same trend was also experienced on traverses 2 and 3 (Figs. 2b and 2c) of the study area which depicts no fractured zone with fairly competent signatures for civil engineering purposes.

4.2 Ground Magnetic Results

The 2D contour map produced in the study area is presented in Fig. 3. A visual inspection of the contour map showed widely spaced contour lines in the study area apart from northeastern and southeastern tips which showed different orientations from the generalized contour arrangement in the study area. The wide spacing of the contour lines depict that the depth to biotite or biotite muscovite granite in these locations is relatively deep (i.e. overlain with thick overburden). Closely spaced contour lines at northeastern tip depict a shallow depth to bedrock. However, the linear subparallel orientation of contour lines at the northeastern and southeastern tips suggest shallow subsurface planar features such as faults or localized fractured zones passing through part of the study area.

The magnetic data were presented as seven profiles (Figs. 4a to 4g). The advantage of profile presentation over grid-based presentation is that geological details are being revealed easily on profiles compared to grid-based presentations. Spikes were experienced across the profiles which are probably due to the presence of magnetic bodies in the subsurface. The magnetic highs represent the presence of mineral rocks in the subsurface while the magnetic lows are due to the presence of planar features such as fracture, fault or contact between two rocks. These magnetic high zones are good for civil engineering activities while the magnetic low zones are probable zones for hydrogeological purposes if explored properly.

The magnetic peaks on each profile were used to estimate depth to magnetic sources. The estimated depths derived from traverses 1 to 7 were summarized on Table 1. From Table 1, mineral rocks with very thin, intermediate, and very thick bodies have their depths range as 14.7 m, 11.0 m and 8.8 m respectively. On the average, the depths to these mineral rocks from the surface ranged from 6.5 to 19.6 m. However, Peter did not specify from this method the shape of the buried body. He assumed that there could be a deformation of these mineral rocks due to some factors such as tectonic stress, weathering etc. He gave the possible geometry of the mineral rocks through the index values or proportionality factor. The shallower the depth, the thicker the body of the mineral rocks and the anomaly will be more pronounced and vice versa.

Seven geomagnetic sections of the study area presented on Figs. 5a to 5g were generated based on the weighted average of the geology and the inferences from the geophysical results. Geomagnetic sections 1 to 3 are in N-S azimuth while the geomagnetic sections 4 to 7 are in E-W azimuth. Bedrock elevation and depression noticed across all the geomagnetic sections has revealed the true inhomogeneity nature of the subsurface. Intrusive body was noticed towards the southern part of geomagnetic section 1 (Fig. 5a). The bedrock of geomagnetic sections 5 to 7 was fractured. Two fracture zones that present on Fig. 5e trend in NE-SW and NW-SE orientations, a fracture zone was present on Fig. 5f which trend in NE-SW orientation. Fig. 5g revealed two fracture zones which also trend in NE-SW orientation. The planar features (such as intrusive body and fracture) mapped in the bedrock revealed that the overburden is underlain with some weak zones that would not be suitable for the construction of high-rise buildings. The bedrock is also overlain by thin-to-thick overburden (an overburden thickness ranged from 6.5 to 19.6 m). However, some fracture zones identified along traverses 5 to 7 (Figs. 5e to 5g) would be useful for borehole development in Olupona Housing estate. Competent and weak zones for engineering purposes have been revealed on Fig. 6. These zones were selected based on the fracture orientations and the intrusive body mapped in the study area as shown on Fig. 6. The fracture orientations are paramount in engineering and hydrogeological purposes. It determines the direction of flow of water and buildings placed across fracture zones are safer than those placed parallel to it. Based on Fig. 6, the tip of northeastern, southwestern, southern and southeastern regions of the study area are competent for civil engineering purposes. Other regions are considered unsuitable for the erection of high-rise buildings. Borehole development would be successful if the boreholes are drilled along the fractured zones.

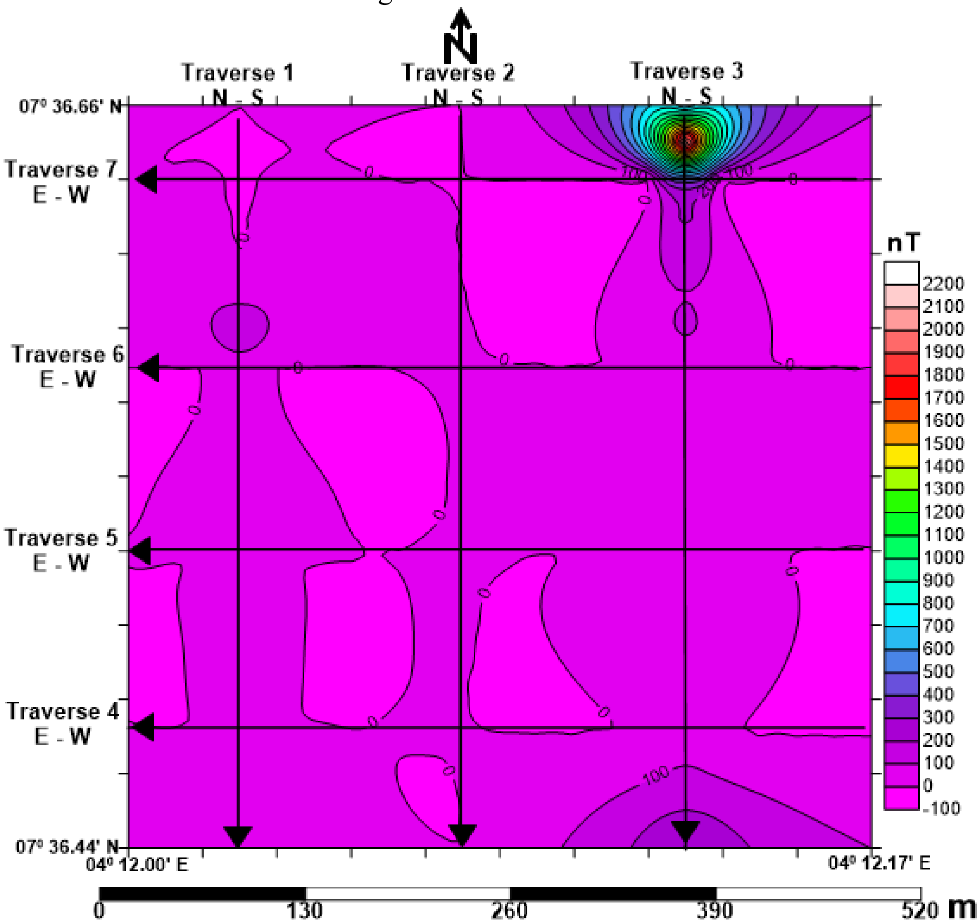


Fig. 3. Total horizontal derivative of Olupona Housing Estate

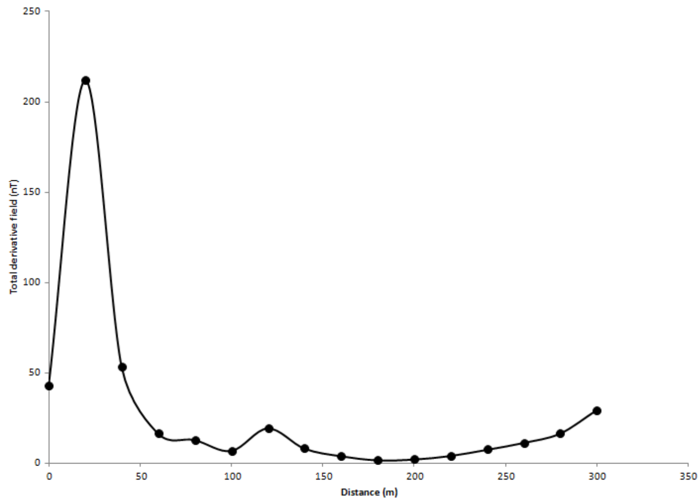


Fig. 4a. Ground magnetic profile along traverse 1 (from north to south)

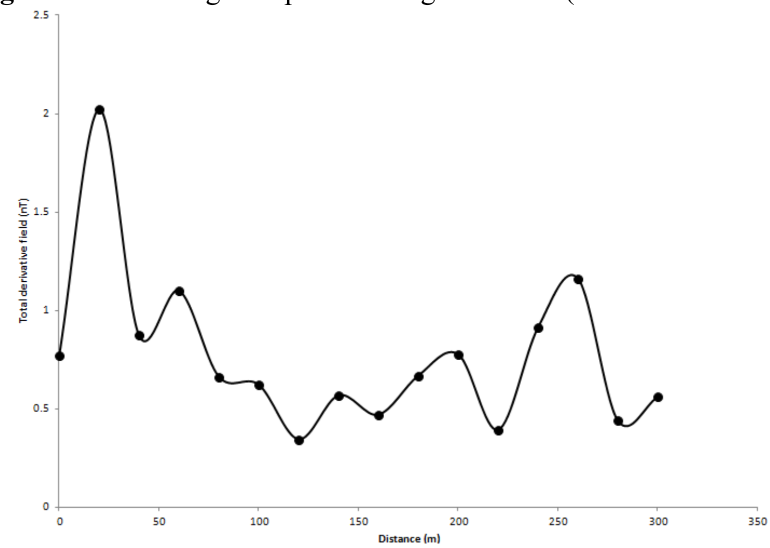


Fig. 4b. Ground magnetic profile along traverse 2 (from north to south)

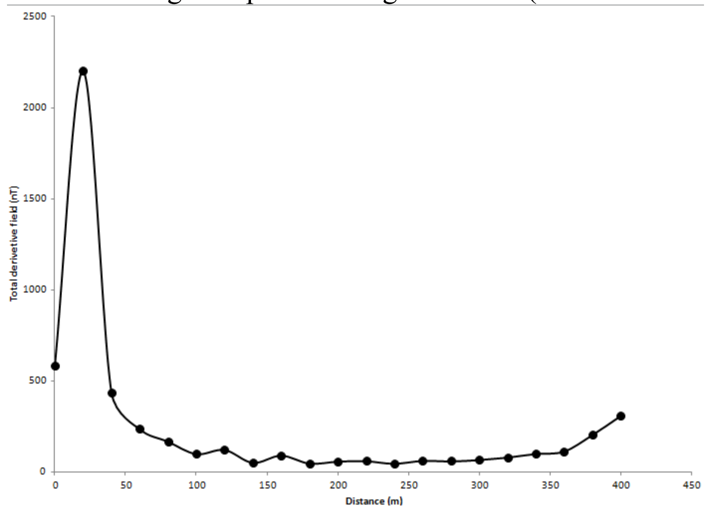


Fig. 4c. Ground magnetic profile along traverse 3 (from north to south)

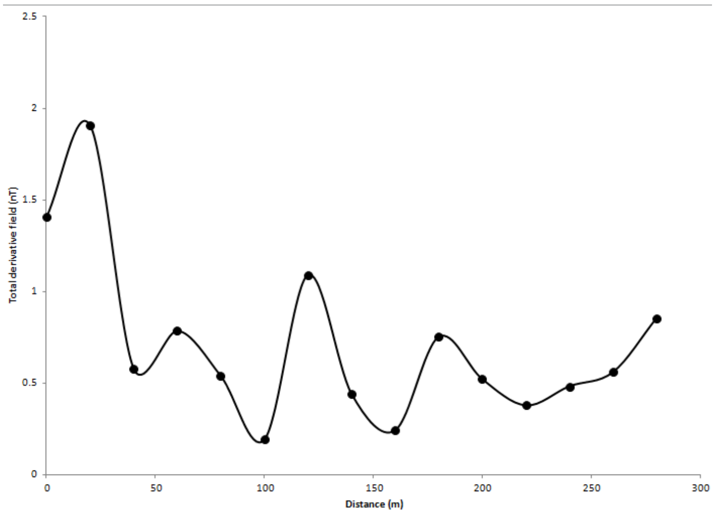


Fig. 4d. Ground magnetic profile along traverse 4 (from east to west)

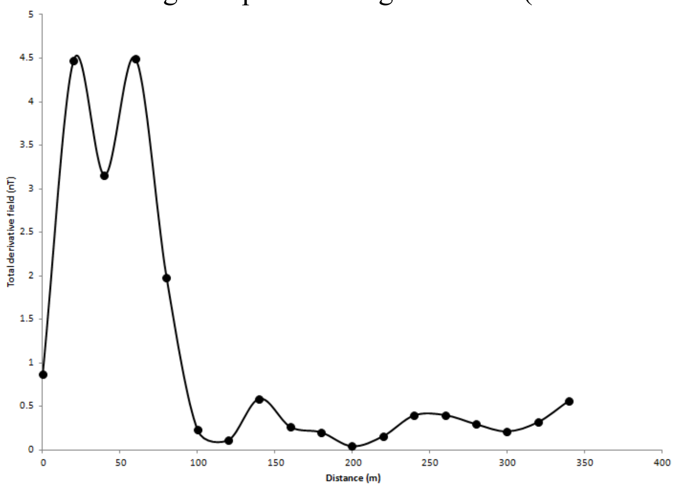


Fig. 4e. Ground magnetic profile along traverse 5 (from east to west)

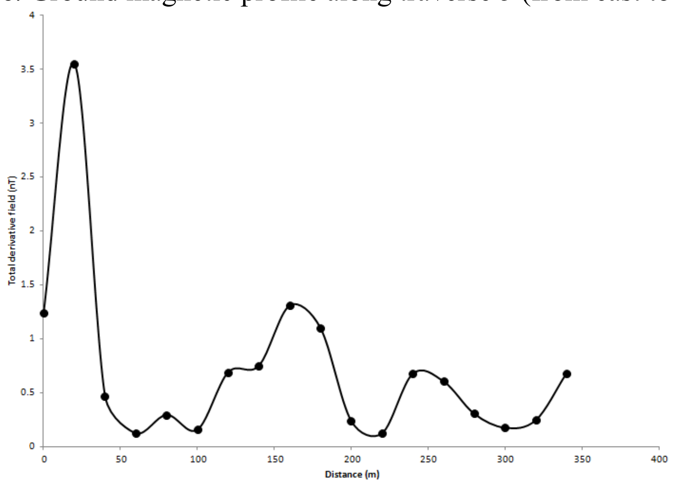


Fig. 4f. Ground magnetic profile along traverse 6 (from east to west)

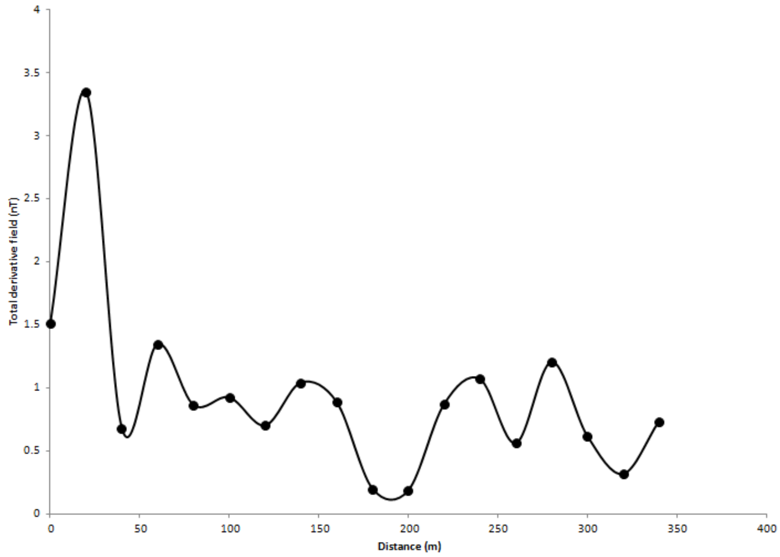


Fig. 4g. Ground magnetic profile along traverse 7 (from east to west)

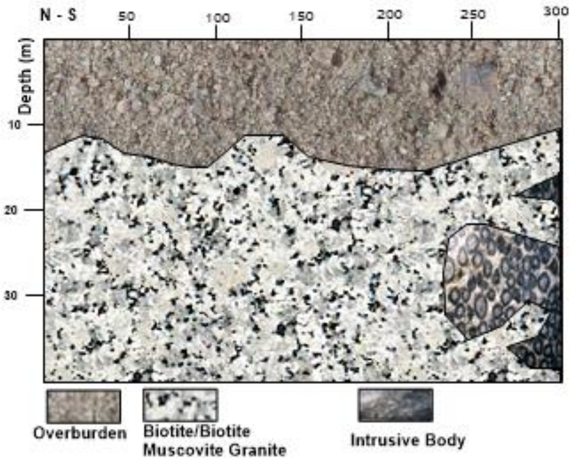


Fig. 5a. Geomagnetic section along traverse 1

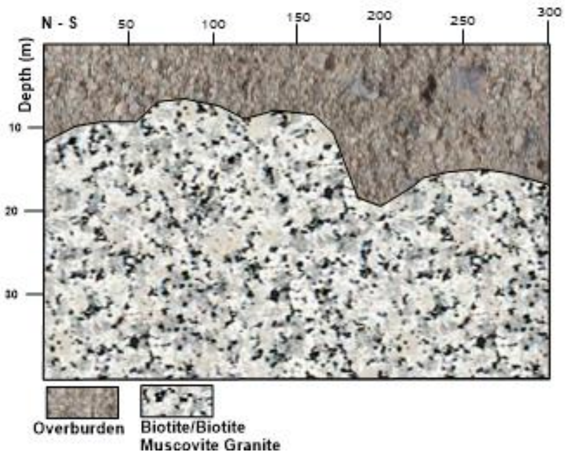


Fig. 5b. Geomagnetic section along traverse 2

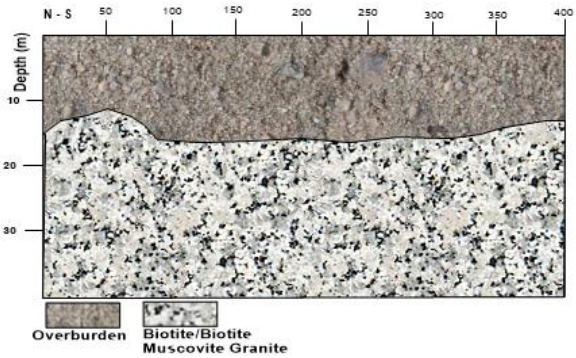


Fig. 5c. Geomagnetic section along traverse 3

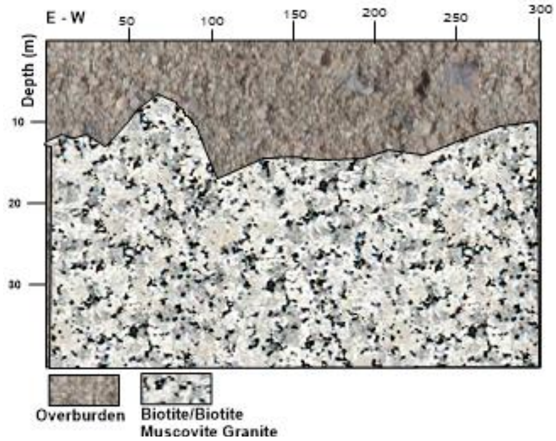


Fig. 5d. Geomagnetic section along traverse 4

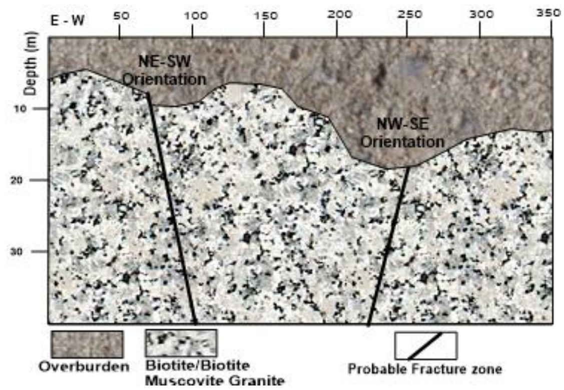


Fig. 5e. Geomagnetic section along traverse 5

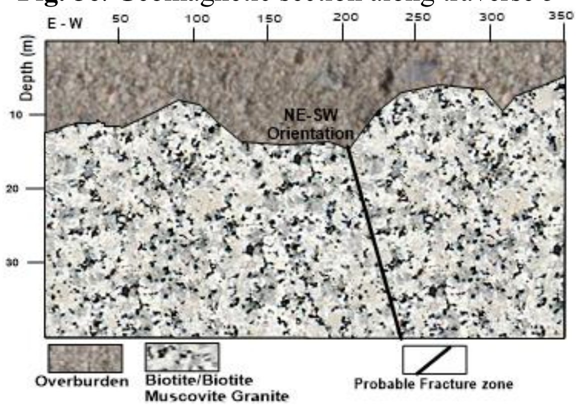


Fig. 5f. Geomagnetic section along traverse 6

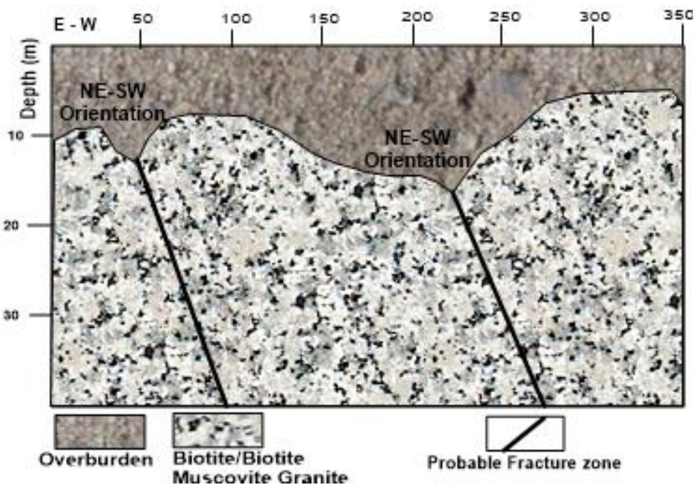


Fig. 5g. Geomagnetic section along traverse 7

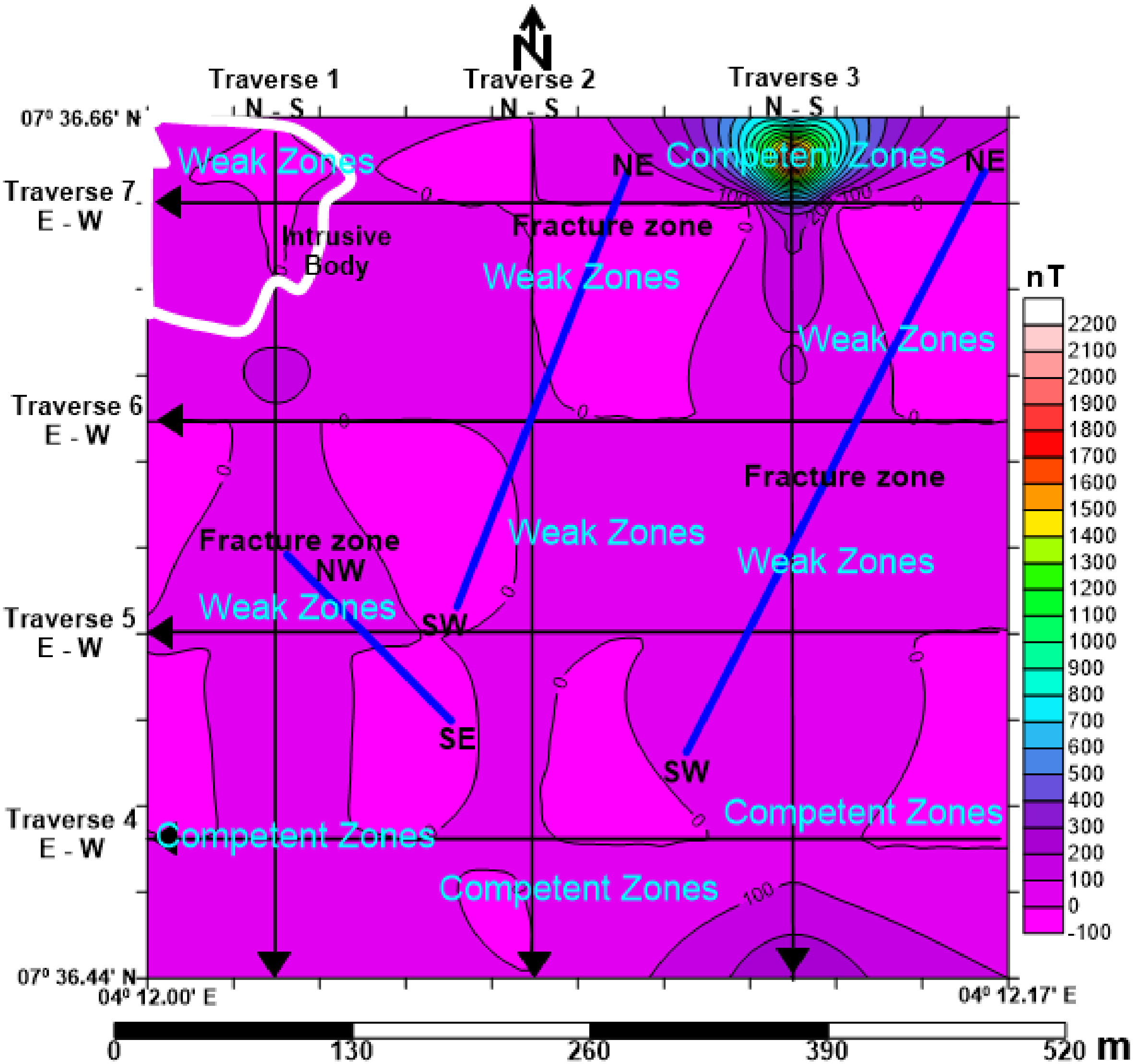


Fig. 6. Composite map of the study area

Table 1. Depth estimates of ground magnetic data from Olupona using Peter's half-slope method

Profiles	Very thin body (m)	Intermediate thickness (m)	Very thick body (m)	Average (m)
1	16.7	12.5	10.0	13.1
	16.7	12.5	10.0	13.1
2	14.2	10.6	8.5	11.1
	10.0	7.5	6.0	7.8
	12.5	9.4	7.5	9.8
	25.0	18.8	15.0	19.6
	21.7	16.3	13.0	17.0
3	17.5	13.1	10.5	13.7
4	15.0	11.3	9.0	11.8
	10.0	7.5	6.0	7.8
	16.7	12.5	10.0	13.1
	16.7	12.5	10.0	13.1
5	8.3	6.3	5.0	6.5
	13.3	10.0	8.0	10.4
	10.0	7.5	6.0	7.8
	20.0	15.0	12.0	15.7
6	14.2	10.6	8.5	11.1
	11.7	8.8	7.0	9.2
	16.7	12.5	10.0	13.1
	12.5	9.4	7.5	9.8
7	12.5	9.4	7.5	9.8
	12.5	9.4	7.5	9.8
	16.7	12.5	10.0	13.1
	16.7	12.5	10.0	13.1
	10.0	7.5	6.0	7.8
Mean	14.7	11.0	8.8	11.5

5. Conclusion

The integrated geophysical technique has proved very useful and cost effective in mapping of fracture type and depth to bedrock estimates which would be useful for civil engineering and hydrogeological purposes in the study area. In order to avoid differential settlement in the buildings that would be constructed there in the future, it is imperative to sound a note of warning that high-rise building constructions should be avoided in the study area. The trends of the identified fractured zones are NE-SW and NW-SE directions.

However, the fracture zones should be maximized for groundwater prospects because if productive boreholes are drilled along fracture zone(s), it would serve other zones that are not underlain by fractured bedrock. In a PreCambrian Basement terrain, the aquifers in most cases are remote and sectionalized, these rocks posses negligible or no primary intergranular porosity and permeability despite being deformed, therefore, groundwater accumulation in the aquifers is basically due to the development of secondary porosity and permeability by weathering and/or fracturing of the parent rocks. The study area could be designed in such a way that water could be channeled to individual house by constructing reservoir(s) that would serve the entire estate for domestic purposes.

Acknowledgement

We appreciate the management of Covenant University, Nigeria for the publication support received from them.

References

[1] George A.M., Abong A.A. and Obi D.A. (2013). Fracture Zone Detection using Very Low Frequency (VLF) Electromagnetic Method in parts of Oban Massif, Southeastern Nigeria. Advances in Applied Science Research, **4**(6): 104-121.

[2] Adagunodo T.A., Adeniji A.A., Erinle A.V., Akinwumi S.A., Adewoyin O.O., Joel E.S., Kayode O.T. (2017). Geophysical Investigation into the Integrity of a Reclaimed Open Dumpsite for Civil Engineering Purpose. Interciencia Journal, **42**(11): 324 – 339.

[3] Ojo A.O., Omotoso T.O. and Adekanle O.J. (2014). Determination of Location and Depth of Mineral Rocks at Olode Village in Ibadan, Oyo State, Nigeria, using Geophysical Methods. International Journal of Geophysics, Article ID 306862: 1-13.

[4] Kayode J.S. and Adelusi A.O. (2010). Ground Magnetic Data Interpretation of Ijebu-Jesa area, Southwestern Nigeria, using Total Component. Research Journal of Applied Sciences, Engineering and Technology, **2**(8): 703-709.

[5] Young C.T. and Droege D.R. (1986). Archaeological Applications of Resistivity and Magnetic Methods at Fort Wilkins State Park, Michigan. Geophysics, **51**(3): 568-575.

[6] Ogungbemi O.S. and Oladapo M.I. (2014). Combined use of Electromagnetic and Magnetic Survey for Hydrogeophysical Characterization of Ijapo Housing Estate, Akure. British Journal of Applied Science and Technology, **4**(7): 1138-1148.

[7] Sunmonu L.A., Adagunodo T.A., Bayowa O.G. and Erinle A.V. (2016). Geophysical Mapping of the Proposed Osun State Housing Estate, Olupona for Subsurface Competence and Groundwater Potential. Journal of Basic and Applied Research, **2**(2): 27-47.

[8] Paal G. (1965). Ore Prospecting Based on VLF Radio Signals. Geoexploration, **3**: 139-147.

[9] Babu V.R., Ram S. and Sundararajan N. (2007). Modeling and Inversion of Magnetic and VLF-EM data with an Application to Basement Fractures: a case study from Raigarh, India. Geophysics, **72**(5): B133-B140.

[10] Gnaneshwar P., Shivaji A., Srinivas Y., Jettaiah P. and Sundararajan N. (2011). Very-Low-Frequuency Electromagnetic (VLF-EM) Measurements in the Schirmacheroasen Area, East Antartica. Polar Science, **5**: 11-19.

[11] Adagunodo T.A., Sunmonu L.A. and Oladejo O.P. (2014). Electromagnetic Investigation into the cause(s) of Road Failure along Takie-Ikoyi Road, Ogbomoso. International Journal of Business and Applied Sciences, **1**(1): 78-85.

[12] Olafisoye E.R., Sunmonu L.A., Ojoawo A., Adagunodo T.A. and Oladejo O.P. (2012). Application of Very Low Frequency Electromagnetic and Hydro-physicochemical Methods in the Investigation of Groundwater Contamination at Aarada Waste Disposal Site, Ogbomoso, Southwestern Nigeria. *Australian Journal of Basic and Applied Sciences*, **6**(8), 401–409.

[13] Adagunodo T.A. and Sunmonu L.A. (2012). Ground Magnetic Survey to Investigate on Fault Pattern of Industrial Estate Ogbomoso, Southwestern Nigeria. Advances in Applied Science Research, **3**(5): 3142-3149.

[14] Adagunodo T.A., Sunmonu L.A. and Adabanija M.A. (2015a). Geomagnetic Signature Pattern of Industrial Layout Orile Igbon. Advances in Architecture, City and Environment, **1**(3): 14-25.

[15] Adagunodo T.A., Sunmonu L.A. and Adeniji A.A. (2015b). An Overview of Magnetic Method in Mineral Exploration. Journal of Global Ecology and Environment, **3**(1): 13-28.

[16] Sunmonu L.A., Olafisoye E.R., Adagunodo T.A., and Alagbe O.A. (2013). Geophysical and Hydro-physicochemical Evaluation of Hand-dug Wells near a Dumpsite in Oyo State, Nigeria. *Archives of Applied Science Research,* **5**(6), 29–40.

[17] Sunmonu L.A., Adagunodo T.A. Olafisoye E.R. and Oladejo O.P. (2012). The Groundwater Potential Evaluation at Industrial Estate Ogbomoso Southwestern Nigeria. *RMZ-Materials and Geoenvironment*, **59**(4), 363–390.

[18] Adagunodo T.A., Sunmonu L.A. and Adeniji A.A. (2015). Effect of Dynamic Pattern of the Saprolitic Zone and its Basement on Building Stability: a Case Study of a High-Rise Building in Ogbomoso. *Journal of Applied Physical Science International*, **3**(3), 106–115.

[19] Oyeyemi K.D., Aizebeokhai A.P., Adagunodo T.A., Olofinnade O.M., Sanuade O.A., Olaojo A.A. (2017). Subsoil Characterization using Geoelectrical and Geotechnical Investigations: Implications for foundation Studies. International Journal of Civil Engineering and Technology, **8**(10): 302 – 314.

[20] Adagunodo T.A., Sunmonu L.A., Adabanija M.A., Suleiman E.A., Odetunmibi O.A. (2017). Geoexploration of Radioelement's Datasets in a Flood Plain of Crystalline Bedrock. Data in Brief, **15C**: 809 – 820. http://dx.doi.org/10.1016/j.dib.2017.10.046

[21] Adagunodo T.A., Hammed O.S., Usikalu M.R., Ayara W.A., Ravisankar R. (2018). Data on the Radiometric Survey over a Kaolinitic Terrain in Dahomey Basin, Nigeria. Data in Brief, **18C**: 814 – 822. https://doi.org/10.1016/j.dib.2018.03.088,

[22] Adagunodo T.A., George A.I., Ojoawo I.A., Ojesanmi K. and Ravisankar R. (2018). Radioactivity and Radiological Hazards from a Kaolin Mining Field in Ifonyintedo, Nigeria. MethodsX, **5C**: 362 – 374. https://doi.org/10.1016/j.mex.2018.04.009.

[23] Adagunodo T.A., Sunmonu L.A., Emetere M.E. (2018). Heavy Metals' Data in Soils for Agricultural Activities. Data in Brief, https://doi.org/10.1016/j.dib.2018.04.115.

[24] Akinwumi I.I., Awoyera P.O., Bello O.O. (2015). Indigenous earth building construction technology in Ota, Nigeria. Indian Journal of Traditional Knowledge, **14**(2): 206–212.

[25] Akinwumi I.I. (2014). Earth building construction processes in Benin city, Nigeria and Engineering classification of earth materials used. Indian Journal of Traditional Knowledge, **13**(4): 686–690.

[26] Arisoy M.O. and Dikmen U. (2013). Edge Detection of Magnetic Sources using Enhanced Total Horizontal Derivative of the Tilt Angle. Yerbilimleri, **34**(1): 73-82.

[27] Cordell L. and Grauch V.J.S. (1985). Mapping Basement Magnetization Zones from Aeromagnetic data in the San Juan Basin, New Mexico, in W.J. Hinze, Ed., The Utility of Regional Gravity and Magnetic Anomaly Maps. SEG, 181-197.

[28] Peters L.J. (1949). The Direct Approach to Magnetic Interpretation and its Practical Application. Geophysics, **14**: 290-320.