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Characterization of Precamrian Basement Formations using Geophysical Methods in Ago-Iwoye Southwestern Nigeria

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ABSTRACT
The characterization of basement rock is essential for obtaining the detailed information for the geological and mineral potential exploration resolves. The study presents the integrated use of electrical resistivity and magnetic methods for characterizing basement rock within Ago Iwoye, Southwestern Nigeria. The study aimed to determine the subsurface geology and alteration of the basement rocks in the area of study and to understand its mineralogical and engineering purposes. The Electrical Resistivity survey was conducted using the integrated of Dipole - Dipole and Vertical Electrical Sounding techniques in order to obtain 1 and 2 Dimensional results. The Magnetic survey used a proton precession magnetometer with a sensitivity of 0.1nT to measure the Magnetic Field Intensity. The acquired data were modeled using inversion techniques to obtain 1-D and 2-DElectrical Resistivity Tomography (ERT) that is capable of unraveling the subsurface information. The results of the electrical resistivity survey revealed a subsurface layer with resistivity values ranging from 600 to 1500 Ohm-m, which correlates with the weathered and fractured layer of the basement rocks. Below this layer, the resistivity increased to a range of 2000 to 8000 Ohm-m, indicating the presence of fresh basement rock. The magnetic survey results showed that the basement rocks have weak and variable magnetic susceptibility values, which suggest weak to moderate magnetite content. The Total Magnetic Intensity (TMI) map revealed that the underlying basement within the study area ranges from 32576- 33404.9nT. The integration of both electrical resistivity and magnetic methods provided a comprehensive understanding of the subsurface geology, structure, and alteration of the basement rocks within the study area. The results revealed that the basement rocks consist of highly resistive fresh rock overlain by a weathered/faulted layer that shows moderate conductivity. The weak magnetic susceptibility values suggest a low magnetic mineral content in the basement rocks.

Keywords:
Characterization,
Basement,
Geophysical,
Resistivity,
Tomography.

INTRODUCTION

Basement complex terrains are regions with a predominance of crystalline igneous and metamorphic rocks that are impermeable. They belong to Precambrian era and possess the characteristics of limited permeability and porosity (Obaje, 2009; Aizebeokhai & Oyeyemi 2018). The characterization of a basement rock involves the integrated use of various geophysical, geochemical and geological techniques in order to unravel the structural composition and properties of the rock. Geological methods involve the study of the rock outcrops and the collection of rock samples for laboratory analysis. These laboratory analyses are meant to describe the petrographic, mineralogical and structural features of the rock. Petrographic analysis allows for the identification of the rock texture, grain size, and mineralogy while structural analysis enables the identification of fractures, faults and other deformations. The basement complex rocks of the West African craton, which date back to the late Precambrian to early Paleozoic orogenesis, and the Cretaceous to recent sedimentary rocks of southwestern Nigeria are what make up

Ogun State's subsurface (Rahaman, 1976). About 40% of the rocks in the crystalline Basement Complex and 60% of the rocks in Ogun State's geology are sedimentary. There are five significant rock groups that make up the Basement Complex rocks in Ogun State (Rahaman, 1988; Ajayi *et al.*, 2022). The most prevalent migmatite-gneiss group is thought to have developed through processes of deformation, shearing, folding, migmatization, and erosional activity. Likewise, the meta-sedimentary and meta-igneous rocks that are either marginally or completely migmatized are regarded to be older than the Older Granite but younger than the gneisses. The Late Precambrian to Early Paleozoic age of the Older Granite rock group is indicated by Oyedele and Bankole (2009). The gneisses and Older Granites contain discordant entities that belong to the dolerite dyke rock group. They are the newest of the rocks in the Basement Complex. The dolerite dykes have a thickness that varies from a few millimeters to roughly half a meter. The stratified rock sequence that makes up the Dahomey basin, which stretches from southern Ghana to the western border of the Niger Delta, includes the sedimentary rocks found in Ogun State. Based on this, the study aimed at determining the subsurface geology and alteration of the basement rocks in the area of study and to understand its mineralogical and engineering purposes. This will also assist to characterize the study area into its geological zones based on its formation.

Location and Geology of the study area

The study area is situated between $06^{o}57^{'}6.6$”and $06^{o}5$’14” latitude and $003^{o}54^{'}27.8$”to $003^{o}5$’46.1” longitude. At a low-lying basement terrain with a topographic elevation of 41to51m above sea level, the study area is situated. High temperatures, high humidity, and heavy rainfall are common in the region, which is significantly influenced by trade winds from the south-west during the rainy season and the north-east during the dry season. Seasonal temperature ranges are roughly 23 to $25^{o}C$ during the wet season and 23 to $30^{o}C$ during the dry season (Akintola, 1986; Oladunjoye *et al.,* 2014). The average annual rainfall is 1750mm, however it can range from1200 to 2300mm. During the preliminary field visit, potential access points and outcrops were evaluated, these included the gathering of the requisite maps (topographic and geology maps), and site inspections (Figure 1). By noting the coordinates of the road systems, geological formations, and significant landmark buildings, a base map of the research area was made. As a rapid reconnaissance technique for locating subterranean structures including faults and fractured zones, the magnetic approach was employed (Olorunfemi *et al.,*2020).

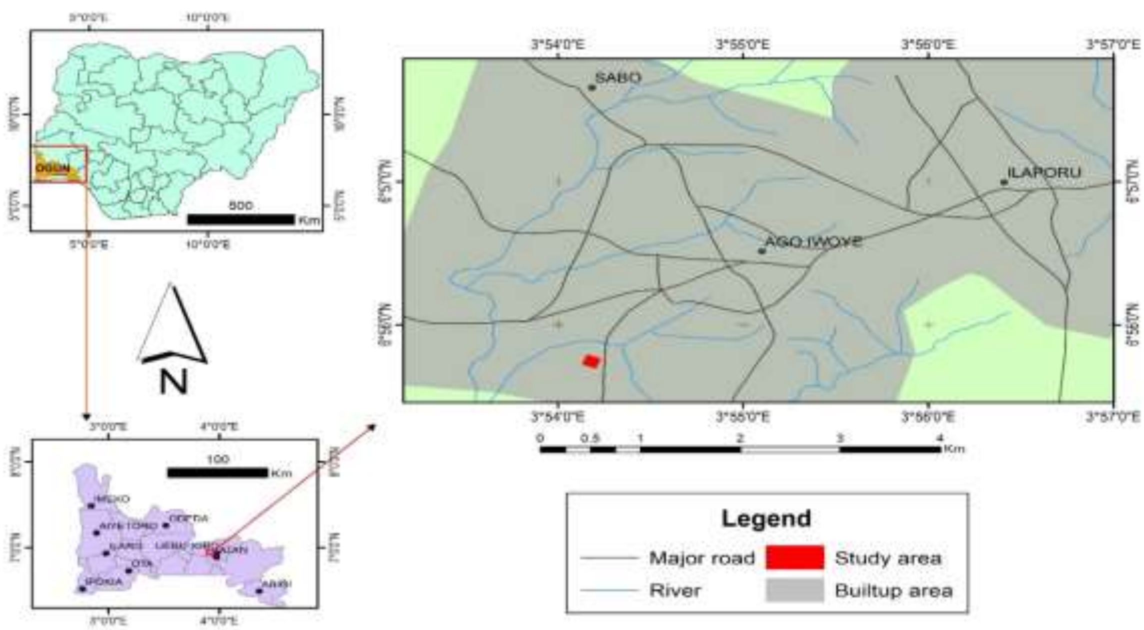


Figure 1: Map of the study area

MATERIALS AND METHODS

The structural characterization was carried out with the integration of geophysical methods comprising of Ground Magnetic and Electric Resistivity Methods with different techniques. The magnetic method data was acquired with the use of Geometries Proton Precession Magnetometer, model GSM 19T on the subsurface. The device creates an absolute and reasonably high resolution of the field and presents measurement in a digital illuminated readout. For the purpose of this study, five traverses were created along the East-North, North-East, and West-East directions with length variations between 50 and 100 m. The Total Magnetic Intensity (TMI) of the area is obtained from the equipment with localized variations in the earth's magnetic field. In order to obtain seamless data during data processing, a base station where the magnetic strengths are being measure data stationary place were chosen within the study location, temporal variations (diurnal variation) in the earth's field during the survey period were observed in order to create accurate magnetic anomaly maps.

Dipole-dipole method of horizontal profiling was deployed to obtain the two dimensional (2-D) electrical resistivity imaging of the study area. Five (5) Horizontal Electrical Profiles were established in form of traverses with spread distance of about

100 meters. The Sounding process were achieved through Schlumberger sounding in order to achieve Vertical Electrical Sounding (VES) within the study area. About thirty (30) VES points were established with electrode spacing of (AB/2) ranged from 1 to 100 m.

The acquired VES data was processed using the art of processing (Soupios *et al.,* 2007; Aizebeokhai & Oyeyemi 2018) with the apparent resistivity, a, which is the product of a geometrical factor, K, and the resistivity obtained during the acquisition of data. The quantitative interpretation used a partial curve matching technique using a 2-layer master curve that was later improved by a computer iteration technique called Resist version, which is based upon an algorithm (Ghosh, 1971; Aizebeokhai & Oyeyemi 2018). The results of the quantitatively analyzed sounding curves were translated into geo-electric characteristics (that is, layer resistivity and layer thickness) (Ilugbo *et al.*,2018).

The acquired magnetic data was presented in the form of magnetic profiles, which involved plotting the magnetic values against the separations between stations on each traverse. In order to provide a more qualitative interpretation, magnetic contour maps (2D plots) of TMI, residual and reduction to equation were obtained. The interpretation process involved examining profiles of magnetic anomalies in regions with low magnetic latitude. The local geomagnetic elements (inclination (I), declination (D), and horizontal magnetic field intensity (H)) derived from the magnetic field calculator (Akintola *et al.,* 2012; Oladunjoye, 2014) were utilized in the modelling of the magnetic fields. A difference of more than 95% between the theoretical profile and the field profile was recorded after the creation of an overburden zone and basement/fault blocks and variation of the susceptibilities of the basement/fault blocks., the regional magnetic field was subtracted from the TMI and recorded as the residual anomaly for each traverse.

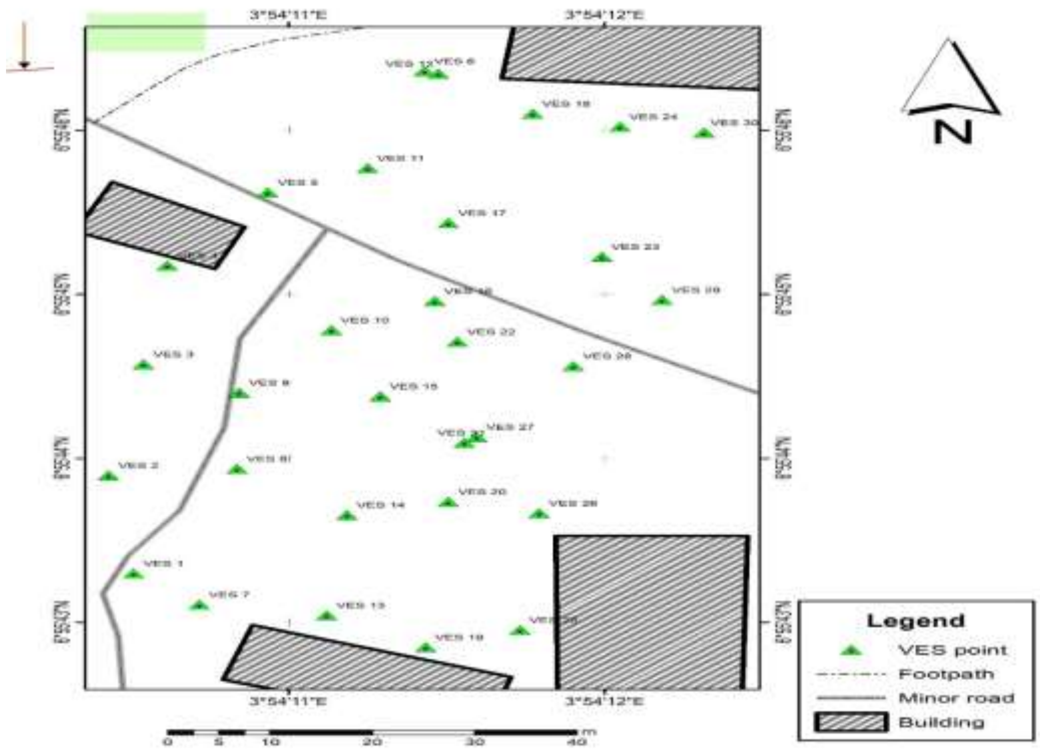


Figure 2: Geophysical Data Acquisition Map

RESULTS AND DISCUSSION

The results of the integrated Magnetic and 2D Electrical Resistivity models were presented as models in Figures 4 - 8. The presentation explicates the lithological sequence underneath the study area. The topsoil, weathered, fractured and fresh basement were described from these models.

Magnetic Susceptibility Intensity

The magnetic susceptibility intensity obtained from the study area as presented in Total Magnetic Intensity (TMI), Reduction to Equator (RTE) and Residual Magnetic revealed a broad spectrum of susceptibility variations as presented in Figure 3a -d. In an attempt to delineate the subsurface structure, the Total Magnetic Intensity (TMI)values described from the processed data ranges from 32576.2-33404.9nT indicating the presence of underlying basement of different structural formation (Figure 3a). The figure represents magnetic intensity variation with high amplitudes how red and pink colours occupying a significant portion and the low magnetic intensity depicted in blue and green colours unravelling the weathered part of the lithology. Further processing carried out on the acquired data resulted to RTE and Residual map. The RTE map (Figure 3c) showed that the acquired map has been corrected with latitude-dependent component and inclination of the magnetic field. RTE maps assists in highlighting the local anomaly in form of weathering and presence of fault line thereby showing better resolution to the structural variation of the basement. The true magnetic susceptibility of the rock present in the surveyed area was obtained via the removal of the regional magnetic intensity (figure 3b) from the total magnetic intensity (TMI). The residual magnetic field (Figure 3d) representing the field of anomalies with short wavelengths and/or shallow features includes anomalies and magnetic discontinuities and other related features. A residual anomaly ranges from-173.7 nT to 1000 nT (Figure 3d) revealed a variation between weak magnetic zone apparently inferred as areas where the sediments are thicker depicting that the basement is deeper within these zones. This geologic formation possesses an extremely negative magnetic susceptibility due to its high quartz enrichment. The field due to long-wavelength anomalies is associated with deeper magnetic feature trends while the field because of abnormalities at low wavelengths is associated with shallower magnetic feature trends generally respectively.

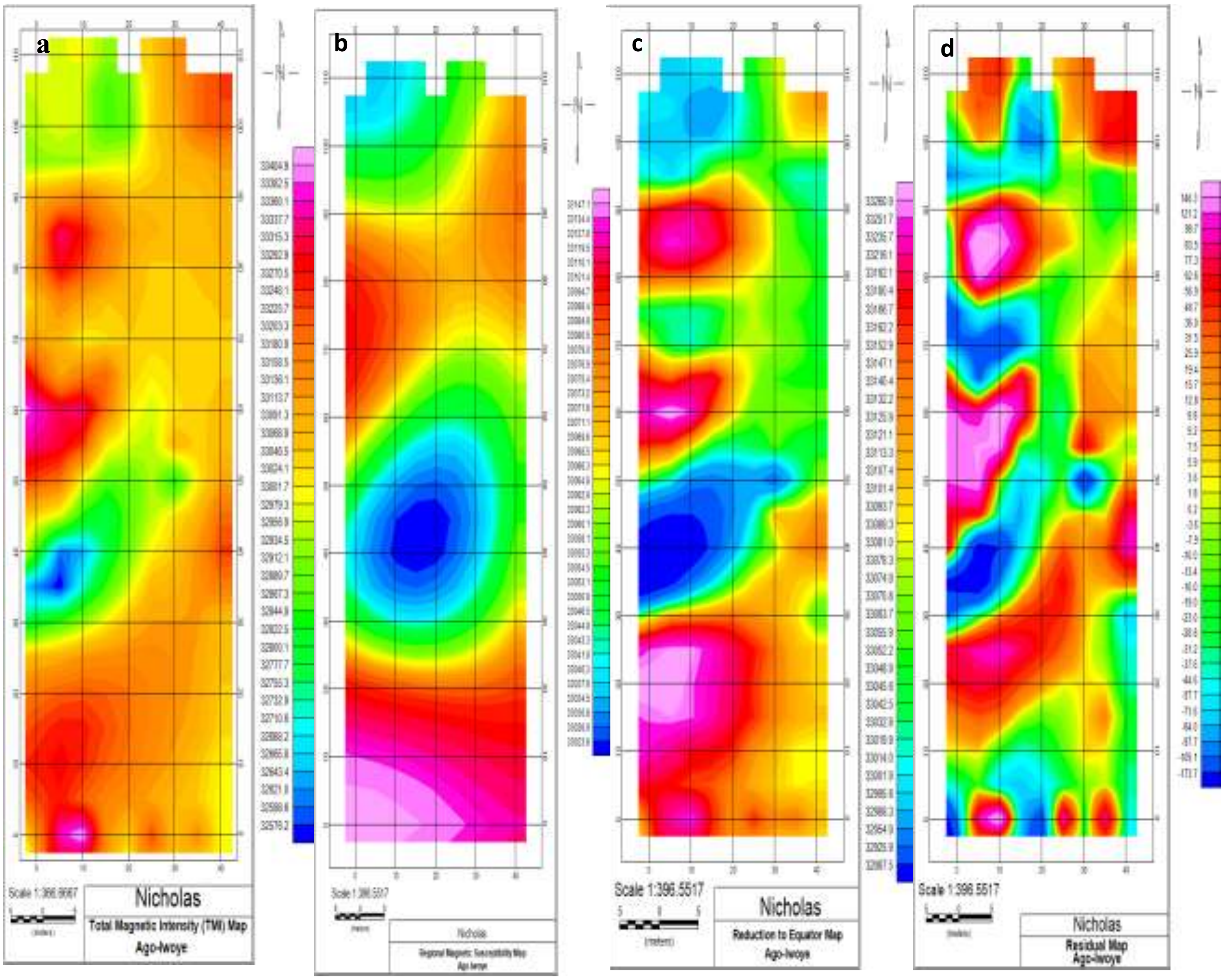


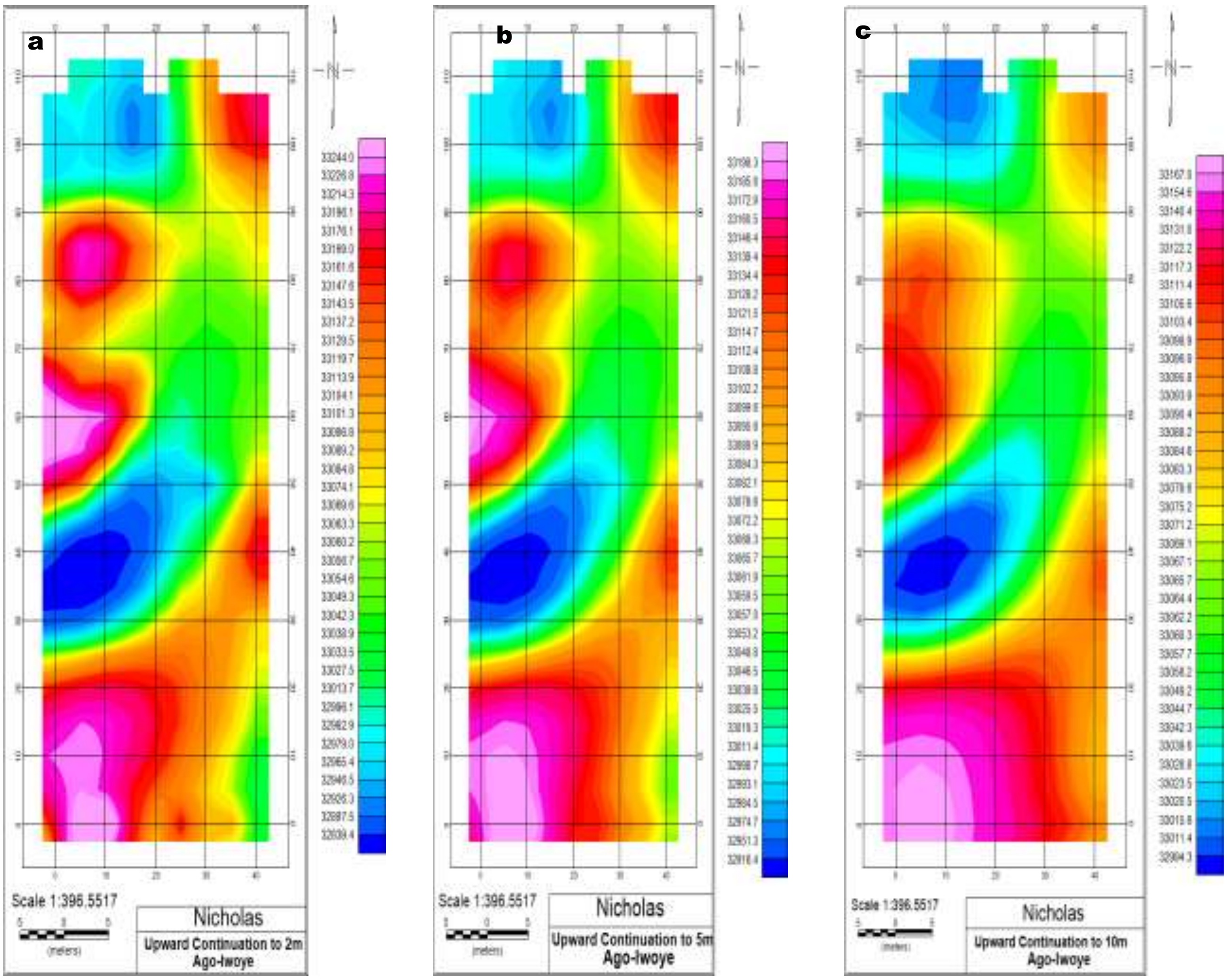
Figure 3: Ground magnetic Models for (a) Total Magnetic Intensity (TMI) (b) Regional Magnetic Intensity (c) Reduction to Equator Map (RTE) (d) Residual Map

Depth Estimation using Upward Continuation Technique

In order to mitigate the impact of shallow anomalies, the residual magnetic intensity was filtered upward continuing the field from 2 – 25 m [Figures 4a – 4f] so as to facilitates the smoothing of high frequency anomalies relative to low frequency abnormalities thereby enhancing deeper signatures from the deeper structures. The upward continuation improves the responses from shallow depth sources by essentially putting the plane of measurement close to the source (Ayenew *et al.,* 2008; Adebo *et al.,* 2019). However, the 2 m upward continuation (Figure 4a) removes signals from very shallow sources that appear to be short wavelength which is disturbing with a large magnitude of the processed data. Hence, a clearer picture of the relatively deeper anomaly source's attenuation targeting 1.5m thickness are obtained.

The upward continuation was further applied to 5m (Figure 4b) in order to obtain the information of the deeper source depth through the removal of short wavelength noises that appear as signals coming from very shallow sources. Consequently, clearer picture of the relatively deeper anomaly sources is a result of the attenuation of the shallow source anomalies in the upward continuation up to the depth of 2.5m

(Figure 4a). Furthermore, the 1 0 m, 15 m 20 m and 25 m upward continuation was displayed on the residual field to further attenuate (i.e. reduce) shallow sources and accentuate (i.e. broad) effects due to the basement (Figure 4c -4 f). Subsequently, Hence, itis very obvious that a clearer picture of the relatively deeper anomaly sources is a result of abnormalities in the upward continuation caused by the shallow source's attenuation. An upward continuation of the magnetic field to 2m, 5 m, 10 m, 15 m, 20 m, and 25 m revealed the limiting depth to basement across the area. All short wavelength anomalies in the area are eliminated at an upward continuation of 25 m.



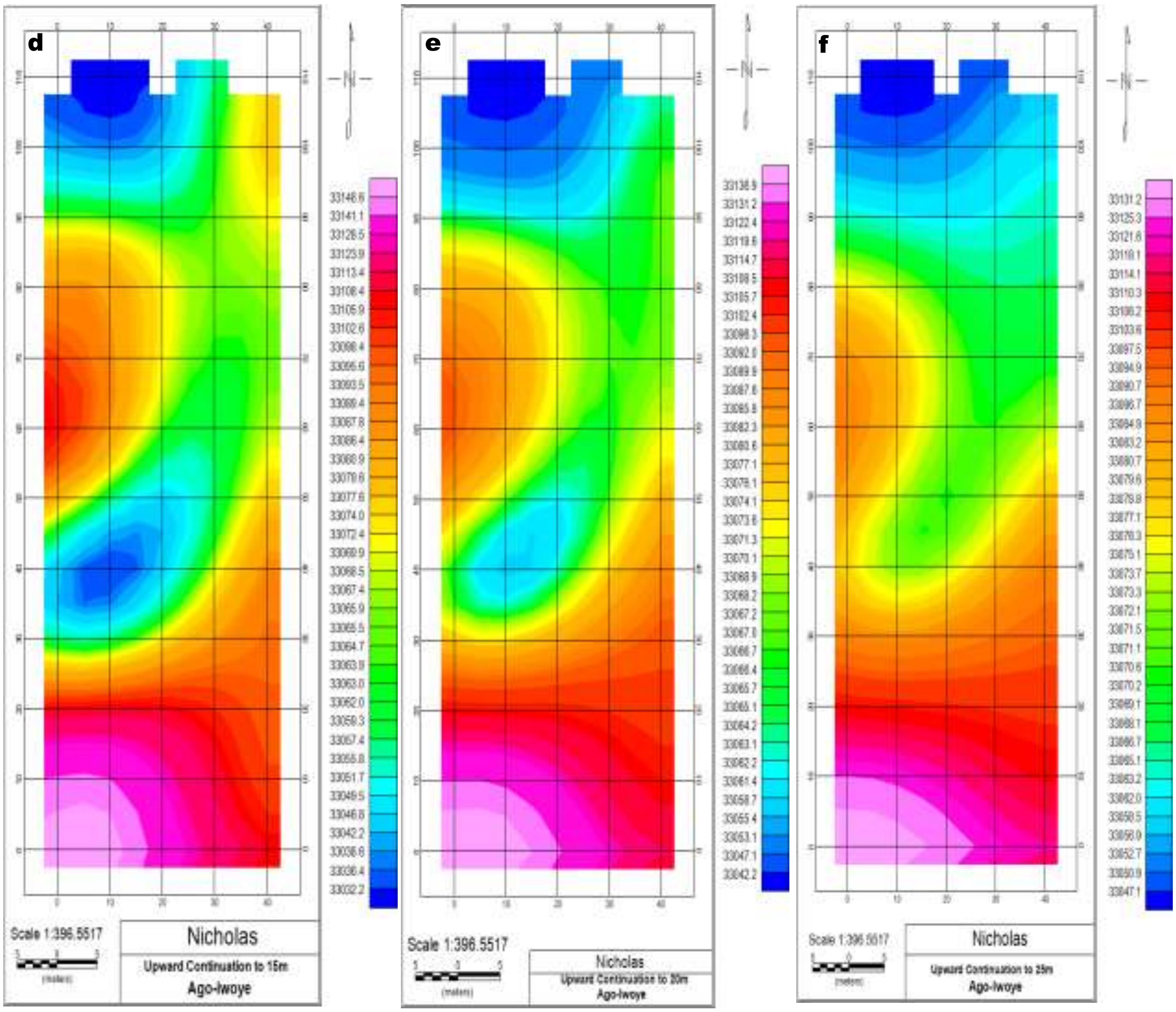


Figure 4: Upward Continuation Map at (a) 2 m (b) 5 m (c) 10 m (d) 15 m (e) 20 m (f) 25 m

2-D Electrical Resistivity Tomography

The two Dimensional (2-D) Electrical Resistivity Tomography (ERT) obtained in the study area as presented in Figures 5a – 5e describes variation in resistivity values for each geo-electric layer. The ERT describes four (4) geo-electric layers comprising of Topsoil, clayey sand/sandy clay, fractured/weathered basement and Fresh basement. The topsoil delineated from the ERT comprises of the exposed materials across the study area. The clayey layer delineated is described with resistivity value ~ 99 Ωm across all the traverses. The clayey layer is found to be underlying the topsoil with varying thickness of ~ 5 m. Although, this layer is presented in traverses 1 and 2 (Figure 5a – b) with sand sediments in form of sandy clay/clayey sand with resistivity values that loiters between 100 - 550 Ωm. The occurrence of these sediments contributes to the stability of these traverses during engineering construction as suggested by Elawadi et al. (2006). These traverses were underlained by basement rock with resistivity values ranging from 650 – 3500 Ωm complimenting the stability of the traverse for engineering purposes. In order hand traverse 3 (Figure 5c) shows the presence of fault line which is capable to be inimical for engineering construction, the fault line is manifested at a lateral distance of 45 – 55 m from the starting point. Low resistivity values that range from 50 – 90 Ωm were delineated along this fault line. In traverses 4 and 5 (Figures 5d -e), the topsoil was underlained with weathered basement with thickness of about ~ 6 m. The change from clay to sand to basement is observed at the bottom left and right of the profile with resistivity increasing with depth from the average depth of about 7 m with resistivity values of about 100 to 3000 Ωm approximately. This shows that the aquiferous zones probably be delineated within the sandy region of the profile.

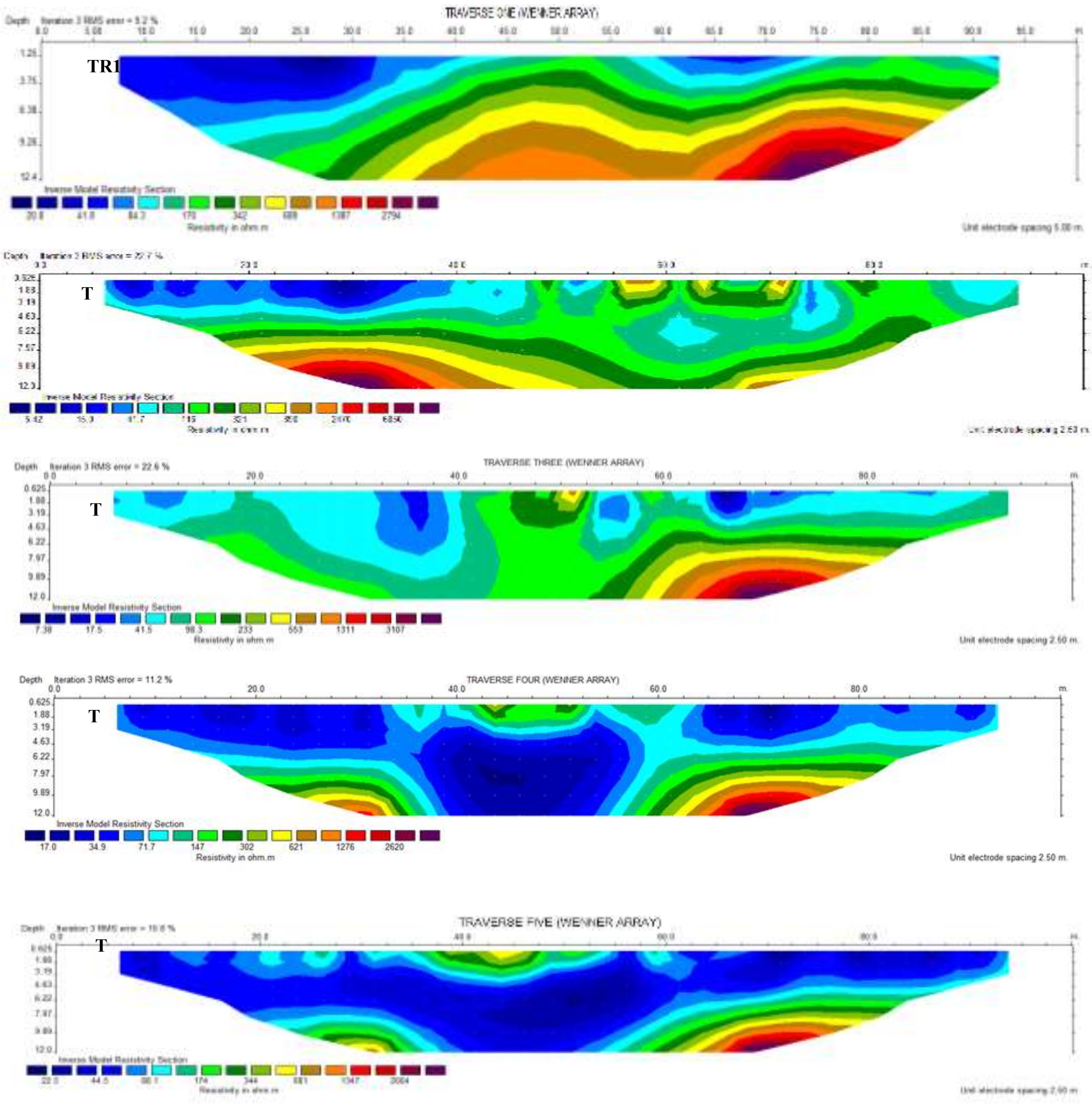


Figure 5: 2-D Electrical Resistivity Tomography (ERT) in the Study Area.

The tomography as obtained has assisted in characterising the lithological sequence of the study area. The basement characterisation showed the extent of basement weathering and the stability of each traverse (Adebo *et al.,* 2019; Akintola *et al.,* 2022). This information can be of help towards exploration, engineering and environmental studies.

Geoelectric Section

The geo-electric section gives the graphical representation of the subsurface electrical resistivity distribution obtained from the Vertical Electrical Sounding technique. The graph gives the description of the stratigraphic arrangement with respect to the thickness of each delineated sediments on each sounding point. The VES points acquired in the study area gives the thickness of the outlined sediments in a bit to understand its geological and hydrogeological implications.

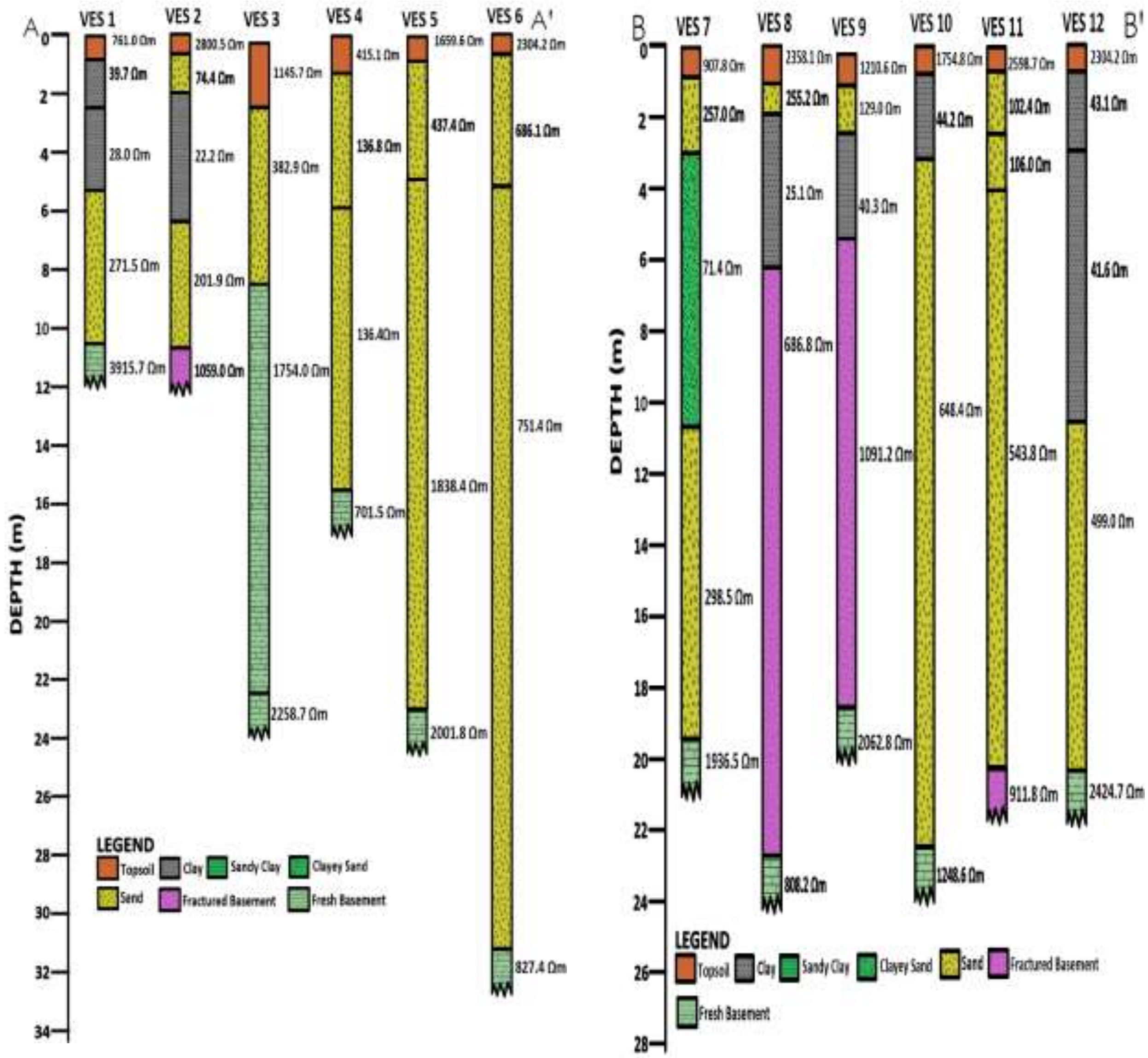


Figure 6: Geoelectric Section of Traverses 1 and 2

The geoelectric section obtained along traverse 1 and 2 are presented as Figure 6a -b. The VES points are obtained at point 100 m, 120 m, 140 m, 150 m and 160 m on each traverse line. The obtained section outlines about six lithologies namely; topsoil, clay, sand, sandy clay, fractured basement, and fresh basement. The lithology delineated are characterised with resistivity values of 415.1 - 2598.7Ωm representing the topsoil, 22.2 - 44.2 Ωm representing the clay formation that is underlain to the topsoil. The lithology outlined by the geo-electric section is described with resistivity values of 102.4 - 686.1Ωm representing the intercalation of sandy clay and clayey sand. The representation of fractured and weathered basement is described with resistivity values ranging from 701.5 - 1059.0 Ωm and 686.8 - 1248.6 Ωm respectively. However, the fractured/weathered basement delineated in VES6 has thickness of about 26 m in VES 6. The fractured/weathered basement layer with resistivity ranging from 686.8 Ωm to 1248.6 Ωm which is 13 - 17.4 m in VES 8 and 9 but their thickness could not be determined due to current termination at this region for the other VES stations. The fresh basement with resistivity ranging from 808.2 Ωm to 2424.7 Ωm but their thickness could not be determined due to current termination at this region (Ndolovu *et al,* 2010).

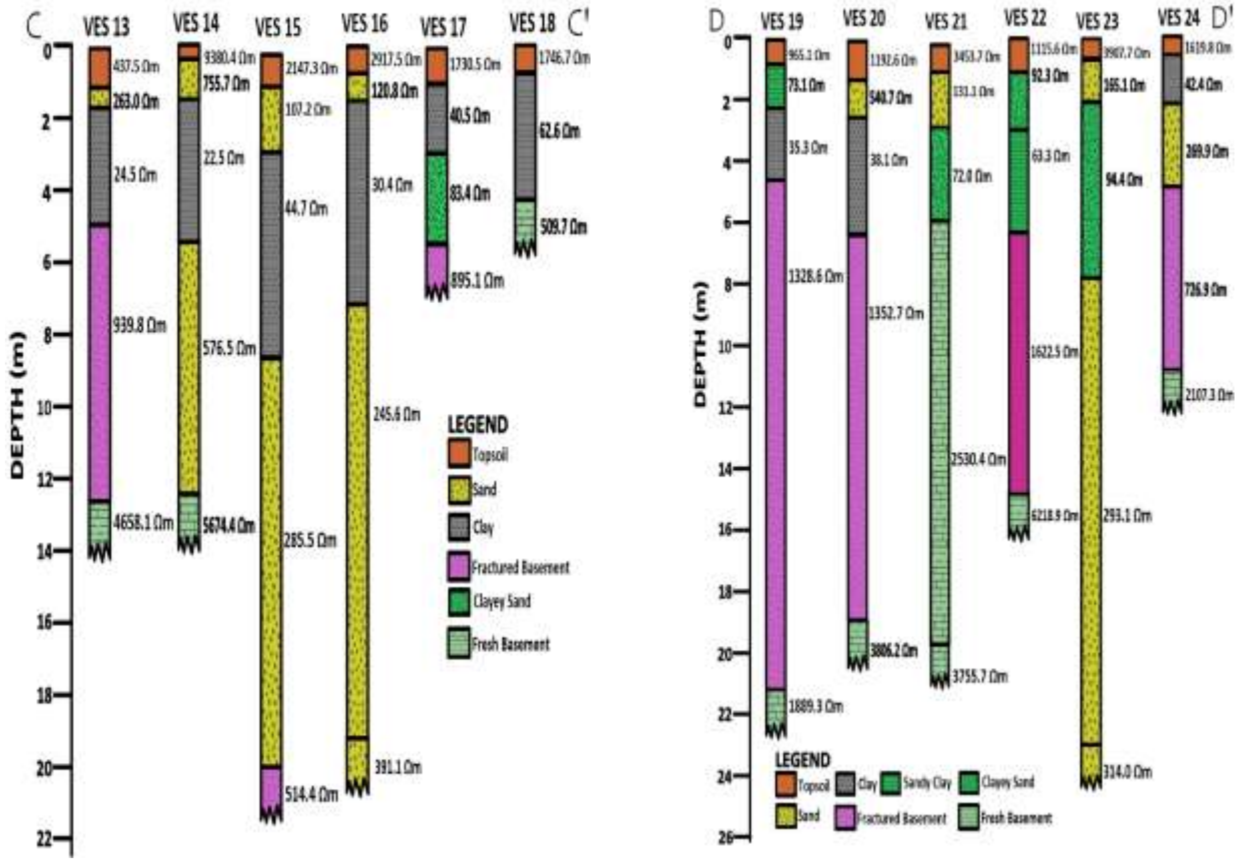


Figure 7: Geo-electric Section of Traverses 3 and 4

Table 1: Interpreted VES Results with Inferred Lithology

VES Station	Geoelectric Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred Lithology
	1	761.0	1.1	1.1	Topsoil
	2	39.7	1.5	2.6	Clay
1	3	28.0	2.9	5.6	Clay
	4	271.5	4.9	10.5	Sand
	5	3915.7	---	---	Fresh Basement
	1	2800.5	0.8	0.8	Topsoil
	2	74.4	1.1	1.9	Sandy Clay
2	3	22.2	4.3	6.2	Clay
	4	201.9	4.4	10.6	Sand
	5	1059.0	---	---	Fractured Basement
	1	1145.7	2.2	2.2	Topsoil
3	2	382.9	6.7	8.9	Sand
	3	1754.0	13.4	22.3	Fresh Basement
	4	2258.7	---	---	Fresh Basement
	1	415.1	1.4	1.4	Topsoil
4	2	136.8	4.6	6.0	Sand
	3	136.4	9.9	15.8	Sand
	4	701.5	---	---	Fractured Basement
	1	1659.6	0.7	0.7	Topsoil
5	2	437.4	4.4	5.1	Sand
	3	1838.4	18.0	23.0	Fresh Basement
	4	2001.8	---	---	Fresh Basement

6	1	2304.2	0.5	0.5	Topsoil
	2	686.1	4.9	5.4	Sand
	3	751.4	26.0	31.4	Fractured Basement
	4	827.4	---	---	Fractured Basement
7	1	907.8	1.0	1.0	Topsoil
	2	257.0	2.0	3.0	Sand
	3	71.4	7.6	10.6	Clayey Sand
	4	298.5	9.1	19.7	Sand
	5	1936.5	---	---	Fresh Basement
8	1	2358.1	1.1	1.1	Topsoil
	2	255.2	0.7	1.8	Sand
	3	25.1	4.1	6.0	Clay
	4	686.8	17.4	23.4	Fractured Basement
	5	808.2	---	---	Fresh Basement
9	1	1210.6	1.2	1.2	Topsoil
	2	129.0	1.0	2.2	Sand
	3	40.3	3.4	5.6	Clay
	4	1091.2	13.0	18.6	Fractured Basement
	5	2062.8	---	---	Fresh Basement
10	1	1754.8	0.8	0.8	Topsoil
	2	44.2	3.1	3.8	Clay
	3	648.4	18.5	22.4	Sand
	4	1248.6	---	---	Fractured Basement

CONCLUSION

The characterization of basement rock using both Electrical Resistivity and Magnetic methods determined the subsurface structure and geology of the area. The Electrical Resistivity Method unravelled the lithology and strata sequence to the basement while the magnetic method on the other hand, was used to measure the rock's magnetic characteristics. Therefore, the incorporated methods are used to establish the depth and thickness of basement rocks. The magnetic method disclosed a diverse arrangement of magnetic abnormalities, suggesting the presence of various sources of magnetization within the underlying rock foundation. Both methods complemented each other in providing a comprehensive understanding of the subsurface structure of the research area. The research concluded that the combined use of electrical and magnetic methods is essential in characterizing basement rock for geotechnical and engineering purposes. The integration method deployed has assisted in defining the subsurface layers for exploration processes such as groundwater potential. Likewise, the results of the magnetic investigation were able to reveal an average basement depth varying from about 20 m which is corresponding to the depth obtained from the electrical resistivity data. The study shows the paucity of basement and the availability. Exploration of granite might be possible following further study of the bulk density of the basement with other geophysical methods. However, groundwater prospecting will be of high yield with the study area as many traverses and VES points such as 1, 2, 4, 7, and 15 are symptomatic of high yield. The aquiferous zones can be found in the fractured basement and possibly in the sand layers sitting directly on the basement.

REFERENCES

Adebo, B., Layade, G., Ilugbo, S., Hamzat, A., and Otobrise, H. (2019). Mapping of subsurface geological structures using ground magnetic and electrical resistivity methods within lead city university, Southwestern Nigeria.*KadaJournalofPhysics*,2(2):64–73.

Aizebeokhai, A. P. and Oyeyemi, K. D. (2018).Geoelectrical Characterisationof basement aquifers:the case of Iberekodo, Southwestern Nigeria. *Hydrogeology Journal*, 26(2):651–664.

Ajayi, O., Konwea, C. I., and Sodeinde, P. O. (2022). Groundwater potential assessment of the sedimentary and basement complex rocks of Ogun state, southwestern Nigeria. *Journal of Water and Environment Technology*, 20(6):248–260.

Akintola, A., Ikhane, P., Okunlola, O., Akintola, G., and Oyebolu, O. (2012). Compositional features of Precambrian Pegmatites of Ago-Iwoyearea Southwestern, Nigeria. *Journal of Ecology and the Natural Environment*, 4(3):71–87.

Ayenew, T., Demlie, M., and Wohnlich, S. (2008). Hydrogeological framework and occurrence of ground water in the Ethiopian aquifers. *Journal of African Earth Sciences*, 52(3):97–113.

Elawadi, E., El-Qady, G., Nigm, A., Shaaban, F., and Ushijima, K. (2006). Integrated geophysical survey for site investigation at a new dwelling area, Egypt. *Journal of Environmental &EngineeringGeophysics*,11(4):249–259.

Ghosh, D. P. (1971). The application of linear filter theory to the direct interpretation of geoelectrical Resistivity sounding measurements. *Geophysical prospecting*,19(2):192–217.

Ilugbo, S., Adebiyi, A., Olaogun, S., and Egunjobi, T. (2018). Application of electrical resistivity method in site characterization along ado–afao road, southwestern Nigeria. *Journal of EngineeringResearchandReports*,1(4):1–16.

Kamba, A., Muhammad, S., and Illo, A. (2018). Basement depth estimates of some part of lower Sokoto sedimentary basin, north-western Nigeria, using spectral depth analysis. *Int J Mar Atmos Earth Sci*, 6(1):1–9.

Ndlovu, S., Mpofu, V., Manatsa, D., Muchuweni, E., et al. (2010). Mapping groundwater aquifer using dowsing, slingram electromagnetic survey method and vertical electrical sounding jointly in the granite rock formation: a case of matshetshe rural area in zimbabwe. *Journal of Sustainable Development in Africa*, 12(5):199–208.

Obaje,N.G.(2009). *Geology and mineral resources of Nigeria*, volume 120.Springer.

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*, 2014.

Oladunjoye, H., Olasunkanmi, N., and Olaleye, A. (2014). Geophysical Evaluation of Magnetic Data of Okenugbo area, Ago-Iwoye, Southwestern, Nigeria. *Academic Journal of Interdisciplinary Studies*, 3(5):105.

Olorunfemi, M. O., Oni, A. G., Bamidele, O. E., Fadare, T. K., and Aniko, O. O. (2020). Combined geophysical investigations of the characteristics of a regional fault zone for groundwater development in a basement complex terrain of south-west Nigeria. *SN Applied Sciences*,2(6):1033.

Oyedele, K. and Bankole, O. (2009). Subsurface stratigraphic mapping using geophysics and its impact on urbanization development in arepo area, Ogun State, Nigeria. *New York Science Journal*,2(2):31–45.

Rahaman, M. (1988). Recent advances in the study of the basement complex of Nigeria. *Pre Cambrian geology of Nigeria*, pages11–41.

Soupios, P., Georgakopoulos, P., Papado poulos, N., Saltas, V., Andreadakis, A., Vallianatos, F., Sarris, A., and Makris, J. (2007). Use of engineering geophysics to investigate a site for a building foundation. *Journal of Geophysics and Engineering*,4(1):94–103