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Integrated Analysis of Geophysical Data for Road Networks Sub Base Lithology Integrity Assessment Case Study in Crystalline Basement Complex, Southwestern Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author IAA designed the research, participated in the field exercise and wrote the first draft. Author AAA participated in the field exercise and discussed the magnetic survey results. Author KAM carried out the literature review and proof read the final draft. Author OOO participated in the field exercise, interpreted the field data and prepared all the figures. All authors read and approved the final manuscript.

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ABSTRACT

Magnetics and Electrical resistivity methods were used in the evaluation of the subsurface integrity of a 2500 m segment of Ipinsa road off the Ilesha-Akure expressway adjacent to the Federal University of Technology, Akure, Ondo State, Nigeria in order to provide guidelines for the authority whenever the road is to be constructed. The road was investigated using geophysical prospecting methods involving Magnetics profiling and Vertical Electrical Sounding (VES) technique. The magnetic data were analysed first by taking care of diurnal variation and the results were presented as relative magnetic. The VES results were presented as geoelectric sections. The results from the two methods were stacked for easy correlation. The results from the Magnetics method study shows the presence of near-surface linear geologic structures and of varying length, depth, and altitude at different distances (350, 550, 650, 840, 870, 900, 1080 and 1160 m) and depths (5, 12, 13, 15, 15.5, 16, 17 and 19 m) respectively, which suggest the probable fracture zones that are

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inimical to the foundation of the road subgrade. The vertical electrical sounding survey were conducted at points of anomaly and non-anomalous zones based on the magnetic survey results. This is done to further delineate the fracture zones and correlate the results to get enough information of the subsurface. The corresponding geoelectric results delineated weathered/fractured bedrock with resistivity range of 222 - 412 Ωm at distances 650, 800 - 900 and 1080 - 1160 m along Traverses A and B. Likewise at distances 1380 - 1600 m, 2040 m, 2240 m, 2260 m and 2540 m along traverses' C and D. The integrity assessment of the Ipinsa road network sub base lithology was successfully assessed using the geophysical modeled results and possible fractured bedrock and saturated/clayey sub soil material zones that are inimical to road stability were delineated. The research findings are valuable for precise decision in road infrastructural design.

Keywords: Magnetic; electrical resistivity; instability; weathered layer and bedrock.

1. INTRODUCTION

Roads are very important for the socio-economic development of any nation [1]. They are very important for the transportation of humans and goods and thus are the major key factor for the national economy [2,1]. Due to the importance of roads, attention must be given to every process of their development which involves preconstruction, construction, and post-construction maintenance [3]. Road failures in Nigeria have severely impacted negatively on the country social economy in terms of huge cost of rehabilitation and loss of lives [4]. With all these severe impacts, all stakeholders; road users and government have been greatly burdened. In accordance with [4,5,6,2], if standard practices are not followed during any of the road construction processes, roads are bound to fail and this may probably be responsible for the continuous failures of roads in Nigeria. According to [6,7,8], causes of road failure ranges from geological, geomorphologic, road usage, non-adherence to standard practices during construction and lack of maintenance culture. Different geophysical methods including electrical, electromagnetic, seismic refraction, ground-penetrating radar methods, and others have been utilized in investigating possible causes of road failures [9,10,11,12,6]. These studies opined that failures could arise from subsurface soils moisture content, clay content and the presence of subsurface structures like bedrock depression, rock contact, sheared, fractured and faulted zones. Geotechnical approaches such as cone penetrometer test (CPT), Atterberg limit, grain size analysis, and cone penetrometer test have also been used [13, 14,15,16,5,4,17]. Integrated geotechnical and geophysical methods in investigating causes of road failure have also been carried out in different locations [9,18,19,20,7,8]. However, none of these works was done on a pre-constructed or an un-tarred road, because focus is usually on post construction investigations. Land magnetic profiling have been used successfully in delineating subsurface structures such as fractures/faults zone, bedrock ridges and depressions [21,22,7] while electrical resistivity method have been used to solve several subsurface characterization problems with a view to investigating possible causes of road failure. This study is therefore aimed at investigating the subsurface condition along an un-tarred road in Ipinsa near Akure Nigeria in order to provide necessary guidelines for the authority whenever the road is to be constructed in the future.

2. STUDY AREA

The study area is 2.6 km long road located off Km1, Ilesha-Akure Expressway to Ipinsa, near Akure Nigeria (Fig. 1). The road is gently undulating with an elevation variation of 392 - 420 m above sea level. The road is between 735623 - 736871 m (Easting) and 808526 - 809631 m (Northing) of the Universal Transverse Mercator. The area is underlain by the rocks of the Basement Complex of Southwestern Nigeria [23]. The lithologic units identified in the area consist of Migmatite-Gneiss, Older Granites and Charnockites [23,17,24,7]. Older Granites and Charnockites exist together as a single body in the entire observed outcrop, while the Migmatite-Gneiss occurs separately (Fig. 1).

3. METHODOLOGY

Reconnaissance survey was carried out at the study area which involved, demarcation of the road into four traverses based on different orientations, staking of measurement positions along the traverses and measurement of coordinates at each station position (Fig. 1).

Magnetics readings were acquired using the Proton Precession Magnetometer The base station was established at the commencement of the investigation. Firstly, the initial base station reading (IBSR) was observed. Secondly, other measurements were observed along the traverses at inter-station interval of 20 m. Two Magnetic readings were observed at each station and the average magnetic reading was used for subsequent analyses. Finally, the base station was re-occupied at the end of the whole measurement for final base station reading. Diurnal variations were calculated for each traverse [25] using the relationship in equation 1.

$$\text{Diurnal variations (DV)} = \frac{\text{FBSR} - \text{IBSR}}{T2 - T1} \quad (1)$$

The derived diurnal variation was added to (if DV is negative) or subtracted from (if DV is positive) the average magnetic reading obtained at each station position. Subsequently, each diurnal corrected station readings were subtracted from the FBSR to obtain the relative magnetic intensity (RMI) value for each station [25,7].

The derived RMI was plotted against the station distance and presented as profiles and geomagnetic sections [25]. The observed anomalies on the profiles which could imply rock contacts and fractures/faults were prioritized as geoelectric sounding points. The freeware Euler deconvolution software was utilized for estimating depth to probable depth of the structures. Structural index of zero was adopted for the fault/critical model. These information were used in producing the geomagnetic section.

The geoelectric sounding data were interpreted using the conventional approach of manual partial curve matching method with the aid of theoretical and auxiliary curves [7,8]. The resultant geoelectric parameters were further refined using Window Resist version 1.0 [26]. The geoelectric soundings results were presented as geoelectric sections and were also stacked with magnetic profiling results for easy correlation.

4. DISCUSSION OF RESULTS

4.1 Magnetic Profiling Results

The results of 750 m long traverse A of Ipinsa road network were presented as a magnetic profile and geomagnetic section (Fig. 2). The magnetic intensity values along the 750 m long traverse varies from -790 to 1670 nT. Magnetic intensity contrast which could be a possible fracture/contact zone occurs at a distance of about 600 m. The profile suggests a magnetically quiet environment to a distance of about 600 m. This section of the road is probably underlain by the same bedrock geology. The corresponding geomagnetic sections produced from the depth estimated by the automated Euler deconvolution techniques assisted in the delineation of three probable fracture/contact zones. Estimated depths of about 12, 13 and 16 m were obtained at distances 350, 550 and 650 m respectively. The possible fracture/fault delineated at the distance of about 650 m coincides with geologic contacts between the Charnockite and Migmatite along the traverse (Fig. 1). The fractured portion of the road falls on the charnockite section which readily weathers into clay and invariably will compromise the integrity of the road if proper precautions are not taken by the engineers.

The results of traverse B Ipinsa road network were presented as magnetic profile and geomagnetic section (Fig. 3). This section of the road spans from distance 750 - 1280 m and the total length of the traverse is about 500 m. The magnetic intensity values range from -445 to 725 nT. Magnetic intensity contrast which could be a possible fracture/contact zone occurs along the traverse with major contrast observed at a section between 800 and 900 m. The magnetic contrast observed at distance 900 - 1280 m is also similar suggesting probably the same lithology. The corresponding geomagnetic sections produced from the depth estimated by the automated Euler deconvolution techniques assisted in the delineation of four probable fracture/contact zones. Estimated depths of about 15, 13, 15.5 and 16 m at distances 840, 870, 1080 and 1160 m respectively were obtained. The structures delineated at the road section between 840 - 870 m suggest the contact between the charnockite and migmatite along the second traverse of the road. The fractured portions of the road fall on the Migmatite and could be inimical to engineering works, and if not properly handled, will contribute to the failure of the road when it is eventually constructed [6,8].

The results of traverse C of Ipinsa road network were also presented as a magnetic profile and geomagnetic section (Fig. 4). The traverse stretches from distance 1300 - 1840 m and has a total length of about 540 m. The magnetic intensity values along the traverse range from - 789 - 300 nT. Magnetic intensity contrast which could be a possible fracture/contact zone occurs along the traverse with major contrast observed at a section between distances 800 and 900 m. A prominent magnetic low was observed at a section between distances 1380 - 1600 m. This observation suggests possible fracture/fault particularly at a distance of about 1450 m. This assertion was corroborated by the Euler deconvolution software that delineated a possible fracture zone at the same distance with a depth estimated to be about 16 m. The inflection point observed at distance 1780 m is probably the boundary between the Charnockite and the Migmatite. The geomagnetic section generally suggests a migmatite rock intruded by charnockite of igneous origin which covers a distance of about 1400 - 1800 m. The fact that charnockite predominantly underlain this traverse of the road may make the proposed road susceptible to failure due to swelling and cracking that is usually observed when road sub-base and sub-grade are underlain by charnockite which readily weathers into clay [5].

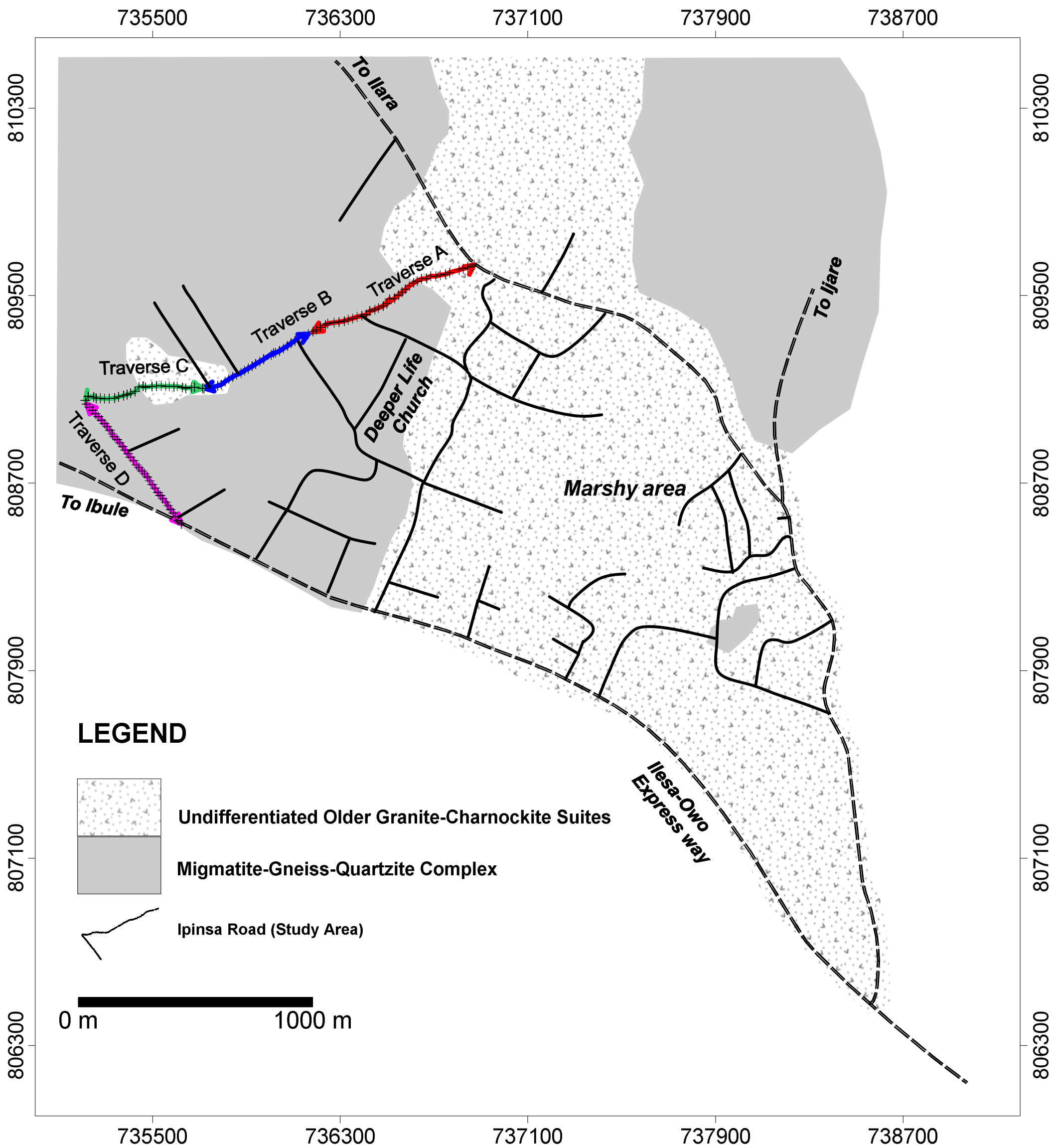


Fig. 1. Geological Map of Ipinsa near Akure, Southwestern Nigeria Showing the Investigated road (6)

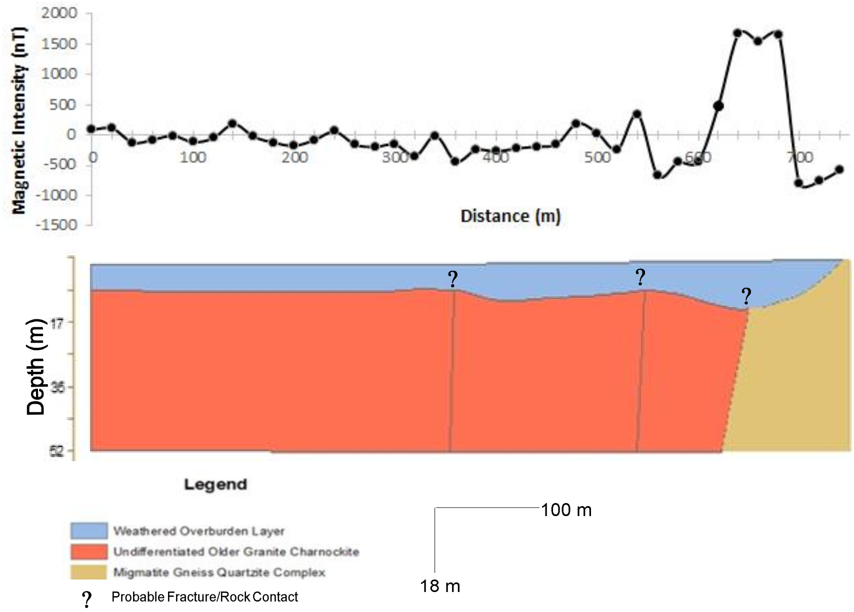


Fig. 2. Magnetic profile and the corresponding geomagnetic section along traverse A of Ipinsa road

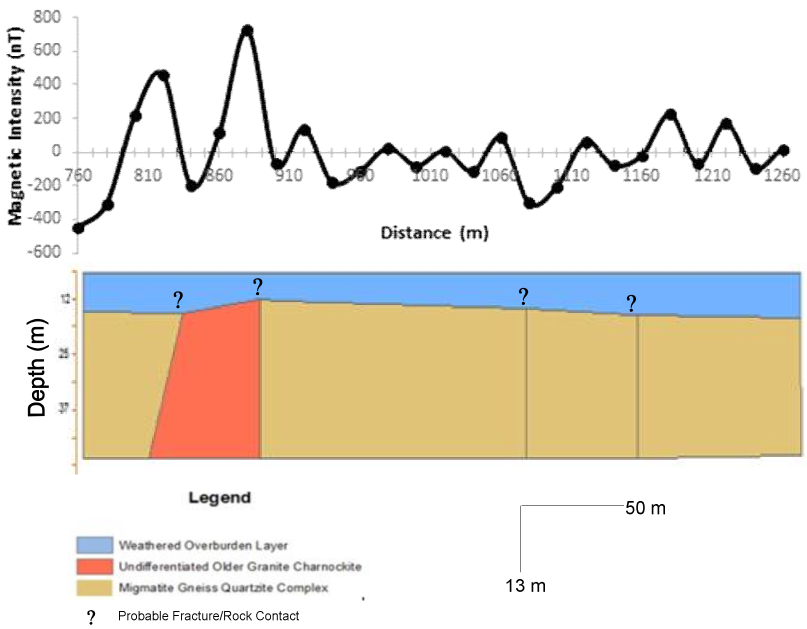


Fig. 3. Magnetic profile and the corresponding geomagnetic section along traverse B of Ipinsa road

The results of geomagnetic survey along traverse D of Ipinsa road network which spans from distance 1860 - 2665 m were presented as a magnetic profile and geomagnetic section (Fig. 5). The magnetic intensity values range from -776 - 173 nT. Magnetic intensity contrast which could be a possible fracture/contact zone occurs along the traverse with major contrast observed at segment between 2200 - 2300 m and this zone coincides with the possible intrusion of charnockite into the migmatite gneiss. The Euler deconvolution estimated possible depths to the delineated fractured/contacts between these rock units as 17, 17.5, 19 and 17 m at distances 2040, 2240, 2260 and 2540 m respectively as observed on the geomagnetic section. The zone delineated at 2540 m is also a boundary between the charnockite and migmatite along this road traverse. The dominance of migmatite on this portion suggests that this section of the road will probably be more competent than the other segments of the road composed mainly by charnockite [4]. However, the intrusion of charnockite at some portions and the presence of fractures may also affect the integrity of the proposed road if necessary engineering precautions are not considered.

4.2 Geoelectric Sounding Results

The geoelectric survey results delineated three to four geoelectric layers along Ipinsa road network namely the topsoil, lateritic layer, weathered layer and the fresh bedrock and their layer resistivities vary respectively from 49 - 214 Ωm, 294 - 741 Ωm, 32 - 200 Ωm and 222 - 5594 Ωm. Three (3) curve types were delineated across the area; the A, H and KH curve types [Table 1 and Fig. 6(a-c)]. The KH curve type is the predominant curve type along this road network and it is characterized with higher resistivity (294 – 741 Ωm). The second layer which is lateritic in nature suggest a relatively stable geoelectric layer [27,6]. The geoelectric survey results were presented as four (4) geoelectric sections, one for each traverse of the road network.

Table 1. Geoelectric sounding results

VES No.	Layer resistivity	Layer thickness	No. of layer	Curve type
1	70/ 73/ 1237	1.8/ 6.5	3	A
2	171/ 196/ 1530	1.2/ 2.2	3	A
3	214/ 200/ 390	1.5/ 3.4	3	H
4	116/ 389/ 95/ 412	0.9/ 1.7/ 9.8	4	KH
5	88/ 548/ 41/ 987	0.7/ 2.1/ 6.9	4	KH
6	106/ 741/ 178/ 5594	0.7/ 7.7/ 31.4	4	KH
7	49/ 531/ 114/ 222	0.9/ 3.6/ 10.3	4	KH
8	147/ 444/ 108/ 4779	1.1/ 2.3/ 33.0	4	KH
9	155/ 508/ 67/ 1000	1.0/ 1.0/ 11.3	4	KH
10	142/ 363/ 32/ 1038	0.9/ 5.9/ 7.3	4	KH
11	87/ 409/ 26/ 2219	1.2/ 4.7/ 15.1	4	KH
12	120/ 294/ 133/ 522	1.3/ 3.3/ 34.9	4	KH

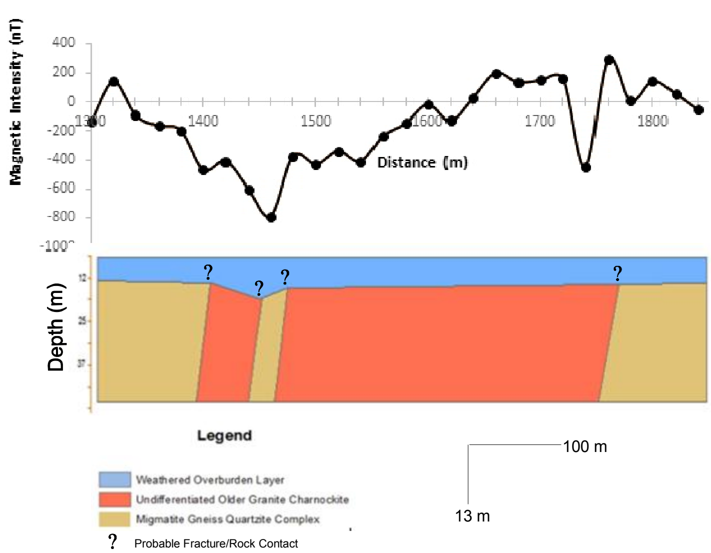


Fig. 4. Magnetic profile and the corresponding geomagnetic section along traverse C of Ipinsa road

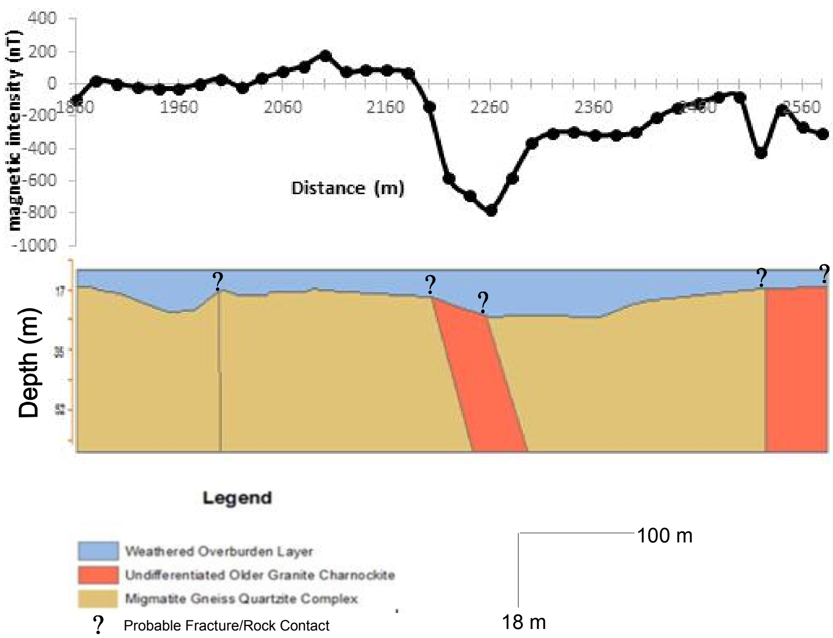
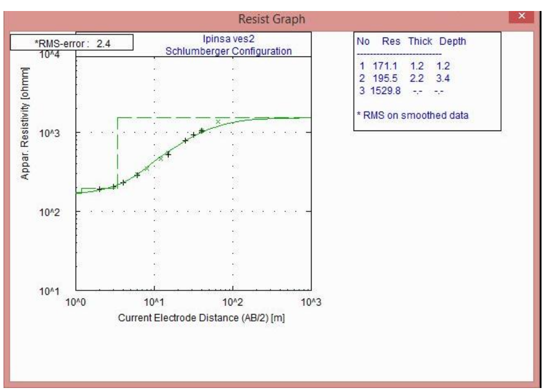
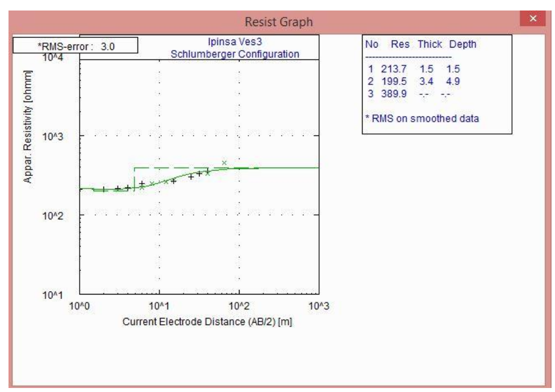


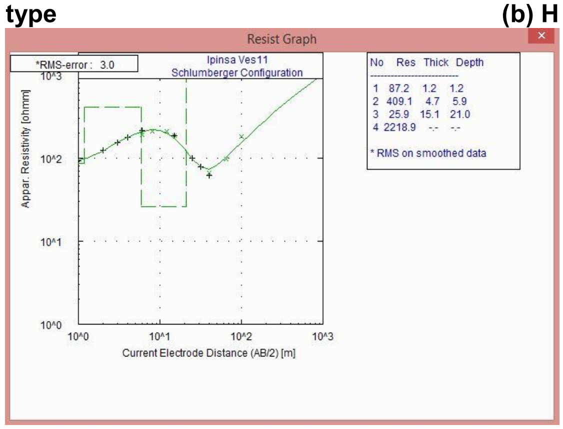
Fig. 5. Magnetic profile and the corresponding geomagnetic section along traverse D of Ipinsa Road



(a) A curve type



(b) H curve type



(c) KH curve type

Fig. 6(a-c). Typical curve types obtained from the studied area

Three geoelectric layers such as topsoil, weathered layer and the bedrock were delineated along traverse A of the Ipinsa road network (Fig. 7). The layers resistivities ranging from 70 - 214 Ωm, 73 - 389 Ωm and 390 - 1530 Ωm, respectively. Relatively low resistivity values (390-412 Ohm-m) were delineated from distance 550-750 m in the bedrock suggesting that the bedrock is either weathered or fractured at this section of the road traverse. This is because bedrock fractures can transmit discontinuity upward to the overlying weathered layer and topsoil, consequently precipitating instability in the overlain road pavement.

Along traverse B of the Ipinsa road network, four geoelectric layers (Fig. 8) were delineated including topsoil, lateritic layer, weathered layer and the bedrock. The layer resistivity values range from 49 - 106 Ωm, 531 - 741 Ωm, 41 - 178 Ωm and 222 - 5594 Ωm, respectively. Relatively low resistivity values (222 Ohm-m) was also delineated in the bedrock beneath VES 7 around distance 1250 - 1260 m which indicates possible change in lithology in the underlying bedrock, from older granite rocks to migmatite-gneiss-quartzite (MGQ) rocks. The lower elevation at these distances might make this portion of the road to be water lodged during raining season.

Similarly, four geoelectric layers were delineated along traverse C of the Ipinsa road network (Fig. 9). The geoelectric layers consists of topsoil, lateritic layer, weathered layer and the bedrock with resistivity values varying respectively from 142 - 155 Ωm, 353 - 508 Ωm, 32 - 108 Ωm and 1000 - 4779 Ωm. The lateritic (363 Ωm) and weathered layer (32-108 Ωm) were characterized with very low resistivities, especially at distance 1800 m (VES 10) where very low resistivity of 32 Ωm was delineated. This low resistivity values could suggest presence of clayey material or highly saturated weathered layer. These two conditions can easily precipitate road instability.

Four geoelectric layers were delineated along traverse D of the investigated road network (Fig. 10). The layers comprise the topsoil, lateritic layer, weathered layer and the bedrock. They are characterized with resistivity values ranging from 87 - 120 Ωm, 294 - 409 Ωm, 26 - 133 Ωm and 522 - 2219 Ωm, respectively. However, the mapped weathered layer at shallow depth is of low resistivity value (26 - 133 Ωm) compared to other layers. Hydro-geologically, such weathered layer is water saturated and thus indicating a shallow groundwater level along this portion of the road. The durability of the road network could be threating by such anomalous groundwater sources formation if neglected during road construction.

4.3 Correlation of Results

The combined results of ground magnetic profiling and geoelectric sounding surveys were as presented in Fig. 11(a-d).

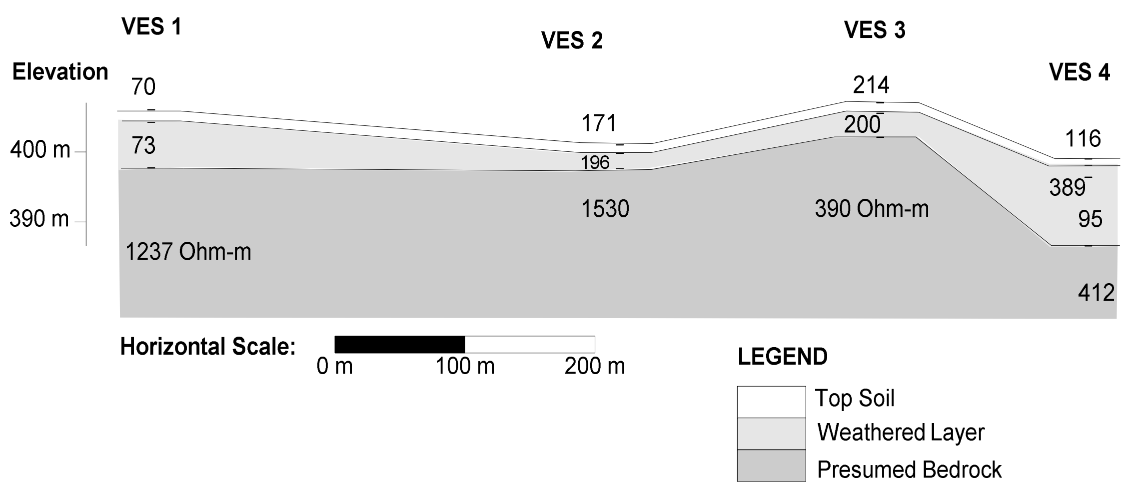


Fig. 7. Geoelectric sections along traverse A of Ipinsa road

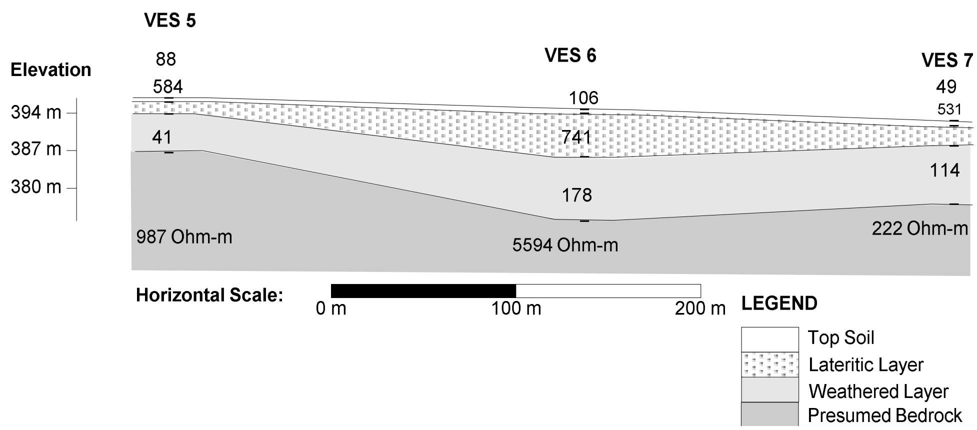


Fig. 8. Geoelectric sections along section B of the road

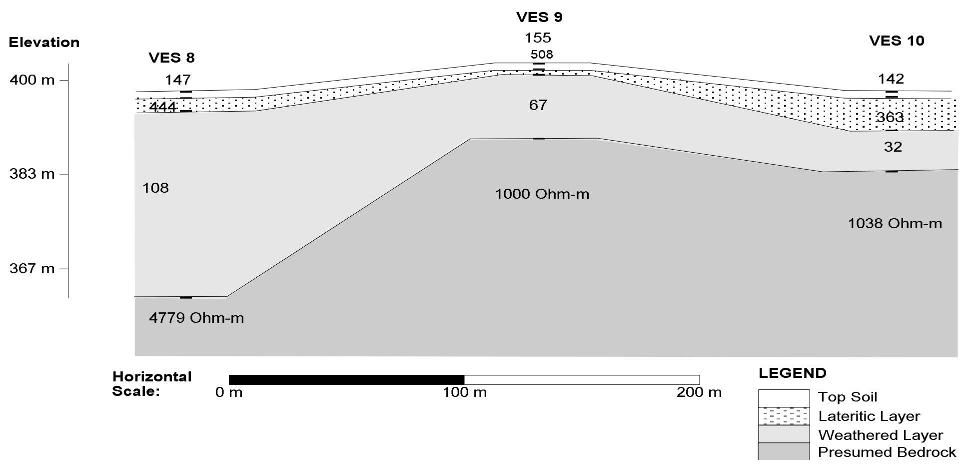


Fig. 9. Geoelectric sections along section C of the road

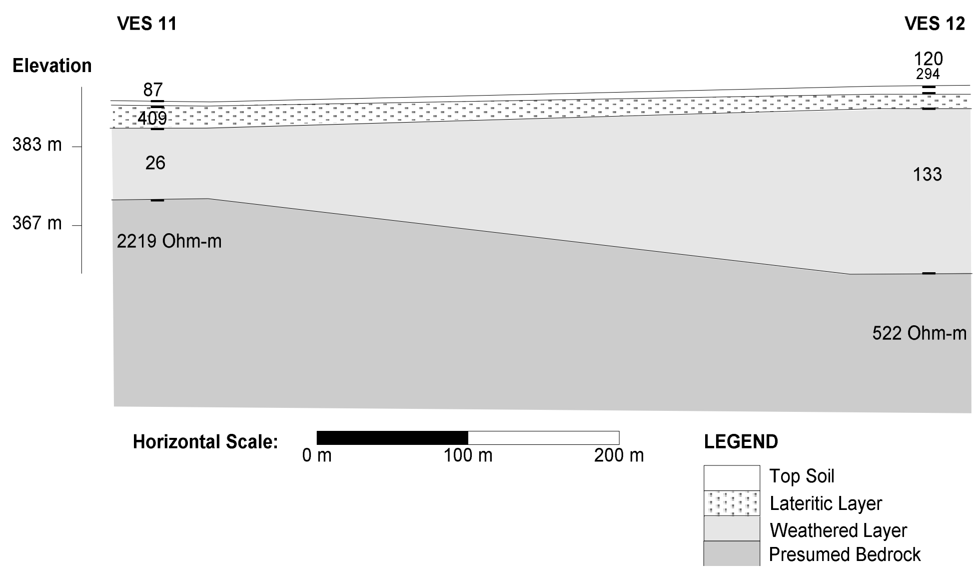
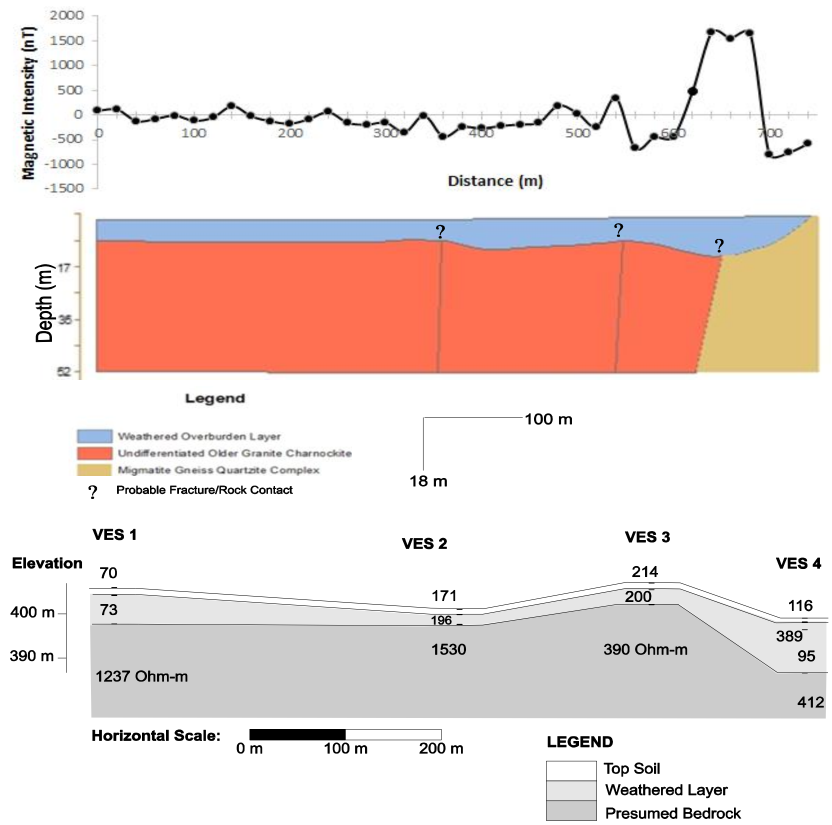
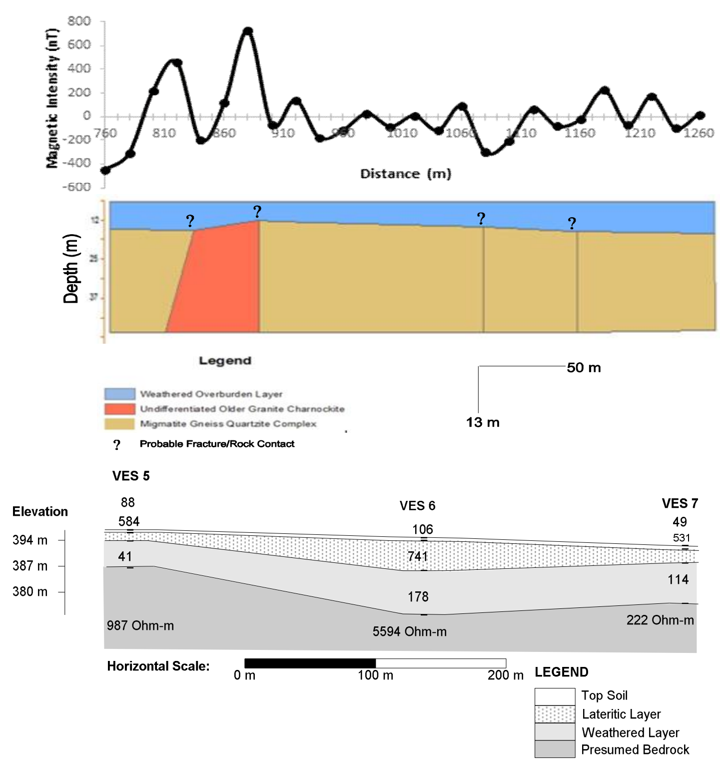


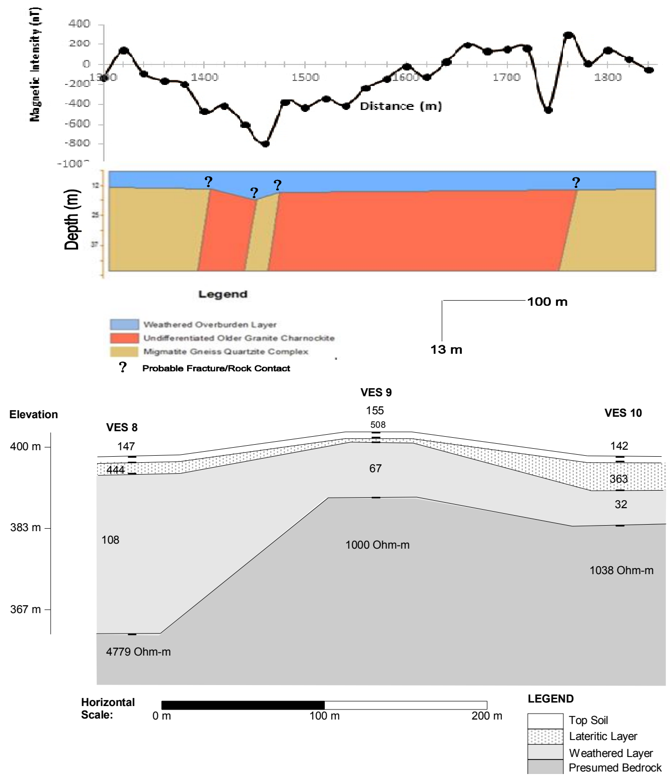
Fig. 10. Geoelectric section along traverse D of Ipinsa road


Magnetic Intensity (nT)
Distance (m)
Depth (m)
Legend
Weathered Overburden Layer
Undifferentiated Older Granite Charnockite
Migmatite Gneiss Quartzite Complex
? Probable Fracture/Rock Contact
100 m
18 m
VES 1
VES 2
VES 3
VES 4
Elevation
400 m
390 m
1237 Ohm-m
1530
390 Ohm-m
412
Horizontal Scale:
0 m
100 m
200 m
LEGEND
Top Soil
Weathered Layer
Presumed Bedrock

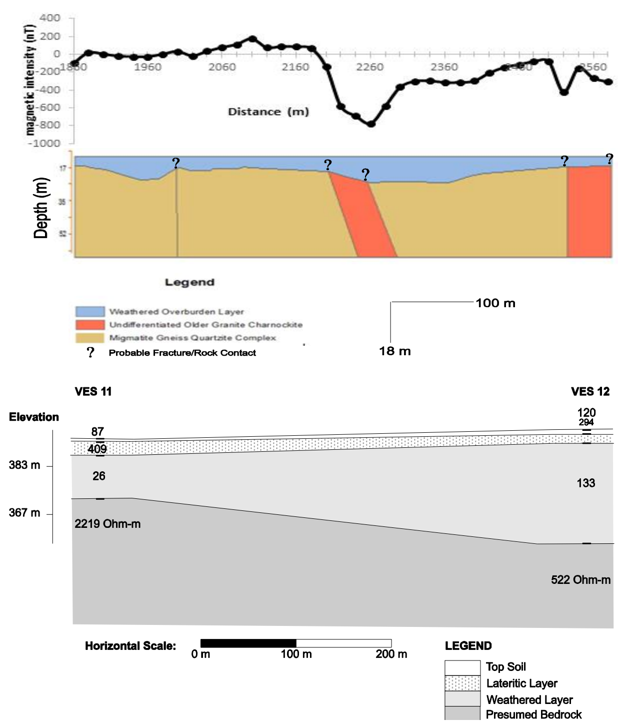
(a)


Magnetic Intensity (nT)
Distance (m)
Depth (m)
Legend
Weathered Overburden Layer
Undifferentiated Older Granite Charnockite
Migmatite Gneiss Quartzite Complex
? Probable Fracture/Rock Contact
50 m
13 m
VES 5
VES 6
VES 7
Elevation
394 m
387 m
380 m
987 Ohm-m
5594 Ohm-m
222 Ohm-m
Horizontal Scale:
0 m
100 m
200 m
LEGEND
Top Soil
Lateritic Layer
Weathered Layer
Presumed Bedrock

(b)



(c)



(d)

Fig. 11(a-d). Correlation results panel showing magnetic profile, geomagnetic section and corresponding geoelectric section along traverses A, B, C and D of Ipinsa road

Along traverse A of the investigated road, bedrock fracture/fault was delineated by both the ground magnetic and geoelectric surveys (Fig. 11a) at distances 560 - 580 m, the RMI values range from -180 to -800 nT while the bedrock resistivity value is 390 Ωm. At distances 700 - 740 m, the RMI value is -420 nT while the bedrock resistivity value is 412 Ωm. Likewise along traverse B, contact between migmatite-gneiss and undifferentiated older granite charnockite rocks was delineated by both the ground magnetic and geoelectric surveys (Fig. 11b). At distances 840 - 860 m and 880 - 910 m, the RMI values range from -180 to -800 nT, while the bedrock resistivity value is 390 Ωm. At distances 700 - 740 m the RMI values vary from -400 to 760 nT indicating a change in lithology from migmatite-gneiss to undifferentiated older granite charnockite. The geoelectric section indicates that the weathered layer at this distance consist of clayey materials as reflected from the very low resistivity value (41 Ωm) obtained at this distance which is the expected end result of charnockite. Along traverse C of Ipinsa road network, bedrock depression was delineated by both the ground magnetic and geoelectric surveys (Fig. 11c) at distances 1400 - 1580 m, the RMI values range from -180 to -800 nT while the geoelectric section revealed a bedrock depression that is about 30 m deep at the same distance range. Also along traverse D of the road network, bedrock depression was delineated by both the ground magnetic and geoelectric surveys (Fig.11d). At distances 2200 - 2460 m, the RMI values range from -200 to -800 nT while the geoelectric section revealed a bedrock depression that is about 20 m deep at the same distances. These high level of correlation further give credence to the efficacy of geophysical techniques as an effective tool in subsurface characterization.

5. CONCLUSION

The subsoil conditions in the study area have been characterized using both the magnetic profiling and geoelectric sounding methods in order to assess the sub base lithology integrity along un-tarred road in a typical crystalline basement complex geologic setting, Southwestern Nigeria. The ground magnetic results were presented as relative magnetic intensity (RMI) profiles and geomagnetic sections, while the geoelectric sounding results were presented as geoelectric sections. Magnetics profiling survey delineated the presence of near-surface linear geologic structures at different distances (350, 550, 650, 840, 870, 900, 1080 and 1160 m) and depths (5, 12, 13, 15, 15.5, 16, 17 and 19 m) respectively. The geoelectric results delineated weathered/fractured bedrock with resistivity range of 222 - 412 Ωm at distances 650, 800 - 900 and 1080 - 1160 m along traverses A and B. Lower resistivities values (26 - 113 Ωm) indicatives of clayey or water saturated materials were delineated at distances 1380 - 1600 m, 2040 m, 2240 m, 2260 m and 2540 m along traverses' C and D. Possible fractured bedrock and water saturated/clayey sub soil material zones that are inimical to road stability were delineated. This study has demonstrated the effectiveness of integrated methodologies in civil engineering work, whereby detailed geophysical evaluations are employed to provide cost-effective ways to evaluate the sub base lithology integrity for road construction. The research findings will be very useful for future decision on the road construction design in the study area and other area of similar geology.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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