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Geophysical and Petrographical Study of Apatapiti Charnockitic Rock, Akure, Southwestern Nigeria

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Abstract

Geophysical and petrographic evaluation of the earth's subsurface is of vital concern, especially prior to geotechnical and hydrogeology works. Vertical Electrical Sounding (VES) of Ire-Akari Estate of Apatapiti Community in Akure South was carried out to assess the effects of the petrographic properties of charnockitic rocks on the geotechnical and hydrogeologic systems. The three curve types identified within the study area are AA, KH and HA, with a predominance of KH curve type, which suggests that the predominant geologic sequence comprising the topsoil has a clayey content alternating with laterite. This is underlain by weathered layer and fresh bedrock. Petrographic analyses revealed the presence of plagioclase (Albite-Anorthite), hypersthene, biotite, quartz, hornblende, microcline, pyroxene and dark-coloured minerals, with an average modal composition of 31%, 15%, 11%, 18%, 13%, 1%, 5% and 6%, respectively. A correlation of both results showed that the topsoil is mostly of about 0.4 m to 2 m thick layer of clay, indicative of weathering of feldspars. This is underlain by 0.8 m to 7 m thick layer of lateritic clay which responds as a low resistive layer. However, the mineral composition at location 1 is characterized by rocks that are more resistant to weathering due to the presence of low plagioclase in the rock sample compared to samples from other locations with a higher percentage of plagioclase and hypersthene minerals. This implies that weathering condition at all locations except location 1 could be favorable to hydrogeology if there are interconnected fractures in the parent rock (charnockite). However, since the area is predominantly covered by clayey materials which are established as poor foundational materials, appropriate ground improvement techniques and in-depth geotechnical analyses should be performed to forestall hazards associated with them.

Keywords*:* Geophysical, Petrographic, Geotechnical, Hydrogeology, Mineralogy, Charnockite

1. Introduction

Geophysical and petrographic assessment of the earth's subsurface is of paramount interest, especially at sites designated for geotechnical and hydrogeology works. This is because geologic structures which are close to the surface, such as cavities, sink holes, voids, fractures, faults, clay pockets and/or heterogeneities which exist in the subsurface geo-materials are major sources of hazards in civil engineering structures [1]. Some of these geologic structures also have a direct influence on the hydrogeology of such sites under study [2]. Therefore, evaluation of petrographic content and geophysical analysis of Ire-Akari Estate of Apatapiti Community in Akure South Local Government Area was carried out towards appraising the influence of the petrographic properties of its rocks on the geotechnical and hydrogeological systems of the area.

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Petrography is the microscopic examination of mineral composition of rocks along with the detailed study of the composition of rock minerals [3]. An earlier investigation [4] explains that laboratory preparation of mineral and lithological samples as thin sections is important in optical mineralogy and petrography. These thin sections are mounted on glass slides and grounded to 30 µm [5] using Michel-Lévy's colour chart on interference [6].

Electrical surveys, which have been employed for decades in hydrogeological, mining, geotechnical and environmental investigations [7], help to ascertain the distribution of resistivity values within the subsurface by taking samples from the earth surface [8]. The resulting data is then used for estimating the true resistivity values [9]. These resistivity values can be correlated with various geological parameters, for instance, the amount of minerals and fluid present, porosity, permeability, and extent of water saturation in the rock [10].

According to previous studies [11, 12], it was revealed that the Charnockitic rock of Akure, Nigeria, are member units of the South Western Precambrian basement rocks.

Therefore, a study of the petrographic properties of these rocks will assist in the assessment of the deformation trait of charnockites, especially within the area of study.

According to an earlier study [13], the first Charnockite within the Nigerian basement terrain was encountered at Toro and further described as a "quartz diorite porphyrite", with a certain similarity to the Ivory Coast charnockitic series. The Toro charnockite is characteristically massive with a greenish-grey to greenish-black colour, as well as fine-grained to medium-grained, equi-granular, and sometimes porphyritic composition [13]. It is usually comprised of minerals such as quartz + plagioclase (Albite-Anorthite) + alkali feldspar + orthopyroxene (or Quartz± fayalite) + clinopyroxene + hornblende ± biotite [14]. Auxiliary minerals are usually zircon, apatite, and ores of iron [15]. Charnockitic occurrences can also be found in localities such as Bauchi, Ekiti (Ado-Ekiti and Ikere-Ekiti), Akure, Idanre, and Obudu Plateau. Various preserved deformational traits observed in the charnockitic rocks of Akure area were reported [11, 12], while the relationship (field and petrographic) between the charnockitic and associated granitic rocks in Akure was established [16].

2. Study Area

The area is characterized by undulating relief and located within Latitudes 7°17'12.92" N to 7°17'13.18" N and Longitudes 5°9'6.16" E to 5°9'5.25" E based on Zone 31 coordinate system with Minna datum (Figure-1) with elevation between 260 to 400 m above sea level [17]. The study covers an aerial extent of about 1200 km^2 [17].

The authors of a previous article [18] established that the study area, located within the tropical rain forest, experiences alternate dry (November to March, with peak temperature of 33 ˚C as highlighted by an earlier work[19]) and wet seasons (mid-March to October, with mean yearly rainfall of 1500 mm and 2100 mm).

The study area is underlain by porphyritic granite and granite gneiss (Figure-1) of the Precambrian Basement Complex of South Western Nigeria [20], which have undergone tropical weathering producing regoliths which are about 3.4 and 13.3 m thick [21], while the underlying basement rock is believed to possess secondary structures (faults, shear zones, fractures and joints) resulting from earlier tectonic actions [22].

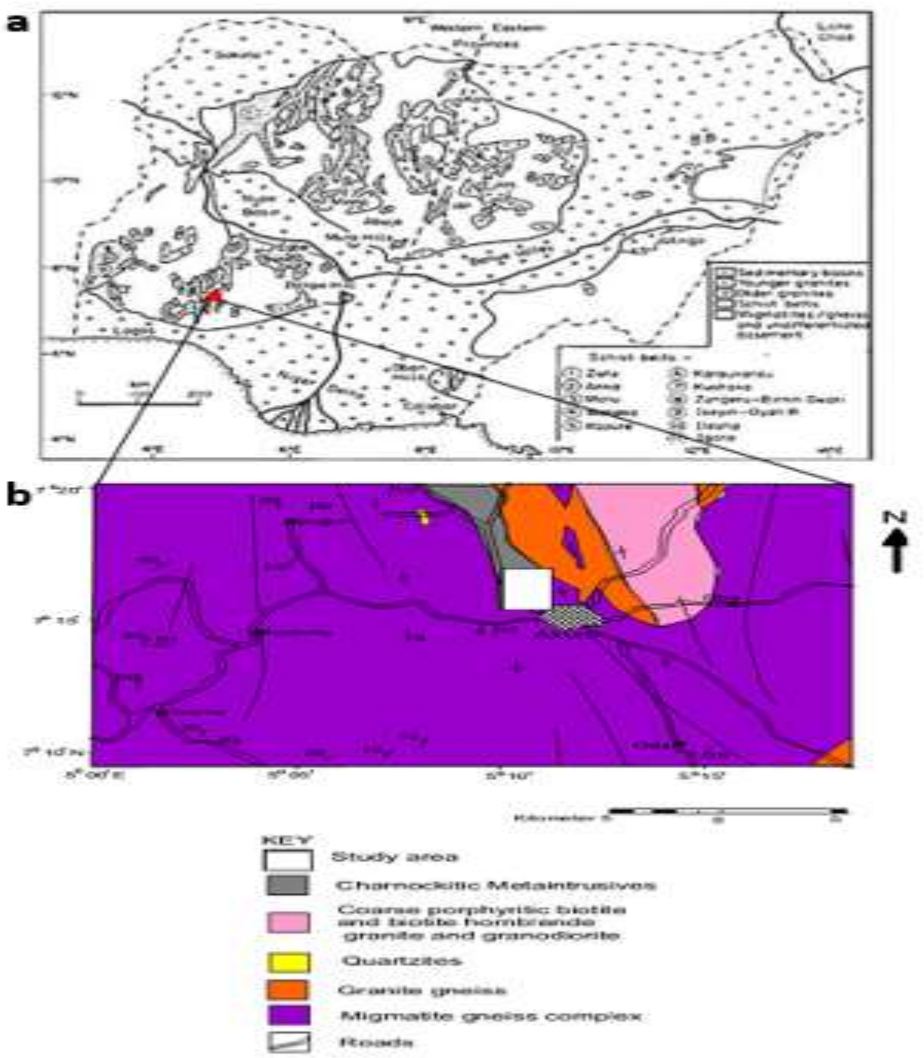


Figure 1- (a) Regional Geological Setting of Nigeria (modified after [11]) and (b) Geological Map of the Study Area (Modified after [12]).

3. Methodology

Vertical Electrical Sounding (VES) using Schlumberger array was employed for this study, with 12 sounding stations. The spread length of the electrode (AB) varied from 2 - 300 m. The instrument used for data collection was Ohmega resistivity meter. Bi-logarithmic graphs were utilized for plotting the measured values of the apparent resistivity against electrode spacing AB/2 to produce field curves. The field curves were visually inspected with various curve types identified. Partial curve matching techniques were also employed for interpreting the field curves, with the interpreted parameters (layer resistivity and thickness) inputted into computer as an initial modeling technique using Win RESIST [22], while geoelectric sections along different directions were produced from the interpretation results.

Afterwards, detailed Petrographic laboratory experiments, such as photomicrograph of the thin sections and modal analyses, of each sample were also conducted. Digital cameras were utilized for taking photomicrographs, with the modal contents analyzed by comparing the photomicrographs with ImageJ.

Data interpretation of the Vertical Electrical Sounding (VES) was carried out using both manual and computer packages, from which maps, charts and graphs that can be used to evaluate both hydrogeology and geotechnical frameworks were generated. The computer packages used were Transfo, ImageJ, WIN-RESIST and Surfer 10.

4. Results and Discussion

After traversing the roads and footpaths within the study area using the GPS, the location map of the area sampled was generated (Figure-2). Rock samples were selected randomly at 6 locations within the study area. Compass-clinometer was used to determine geographic orientation of roads, foot paths and the orientation of lineaments on outcrops in the study area. The textural, mineralogical and structural characteristics, field relationship and mode of occurrence of outcrops were observed, with 12 samples selected at random. The geographic coordinates of the outcrops were converted to Universal Transverse Mercator (UTM) and plotted using Surfer 10.

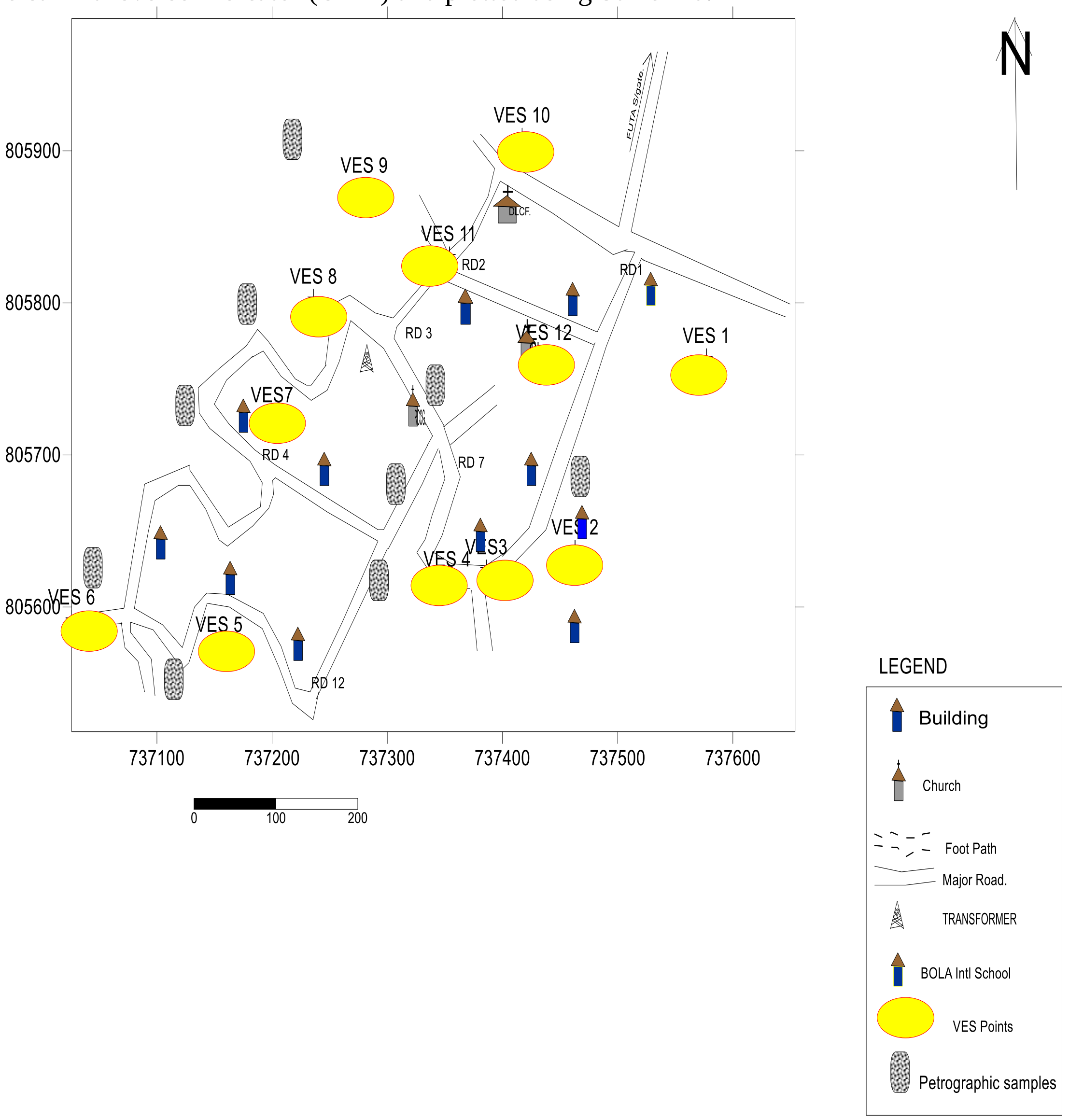


Figure 2- Location map displaying points where rock samples and Vertical Electrical Sounding (VES) were taken.

The petrographic results which were obtained from thin sections are presented in photomicrographs (Plates-1 – 6), using two different views crossed Nicol (XN) and plane polarized light (PPL), while the modal analysis of the mineral composition was also carried out. The point count on stained slabs was carried out in a precise resemblance as in the traditional thin section analysis, and was subjected to a previously proposed theoretical treatment [23]. This theoretical treatment was proven by other authors [24]. Table-1 shows the key to symbols used in the identification of rock minerals in the samples whose microphotographs are displayed in Plates-1 -6.

The outcrop in the study area is predominantly charnockite rock. In 6 samples taken from 6 different locations, the mineral composition of this outcrop after being subjected to laboratory process consisted of plagioclase, hypersthene, biotite, quartz, hornblende, microcline, pyroxene and dark-coloured minerals as key minerals, with an average modal composition of 31%, 15%, 11%, 18%, 13%, 1%, 5% and 6%, respectively (Table-2).

The grains carry inclusions of quartz and some particularly plagioclase which showed albite twinning, some of which were bent or distorted. The hornblende seem to be a secondary development. There are visible undulose exterminations, revealing micro-cracks (Plates-1 – 6).

Hypersthene grains exhibited various cracks while the flakes of biotite carried inclusions of zircon. The microcline mineral occurred in a small percentage of the rock sample and it is only observed in Plate- 2. The dark-coloured minerals are probably modification products of iron oxide, closely related with hornblende and biotite.

Largely, all the minerals detected by the photomicrograph in the thin section slides were irregularly shaped with sutured edges, which suggests weathering. Most charnockitic rock outcrops in this environment were releasing iron (Fe^{2+}) which aids weathering. Also, the photomicrographs (Plates-1 – 6) show the presence of features such as micro-cracks, distorted twinning, bent lamellae, and compressed twin-planes in all the minerals.

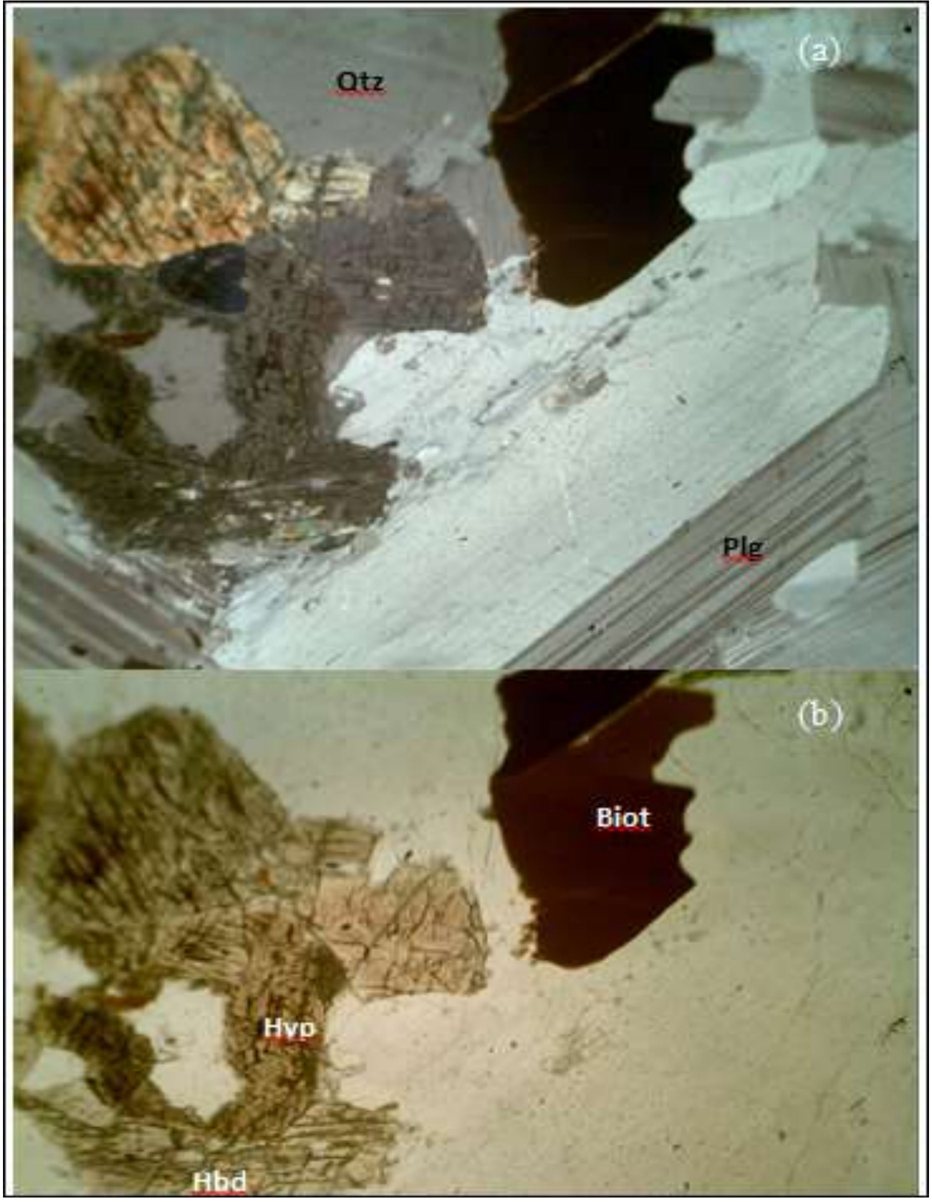


Plate 1- (a) Sample 1 Photomicrograph of Sub Ophitic Texture between Quartz (Qtz) and Plagioclase (PLG) in Glimmerite under Cross Nicol and; (b) Photomicrograph of Hypersthene (Hyp), Hornblende (Hbd) and Biotite (Biot) under Plane Polarized Light (PPL).

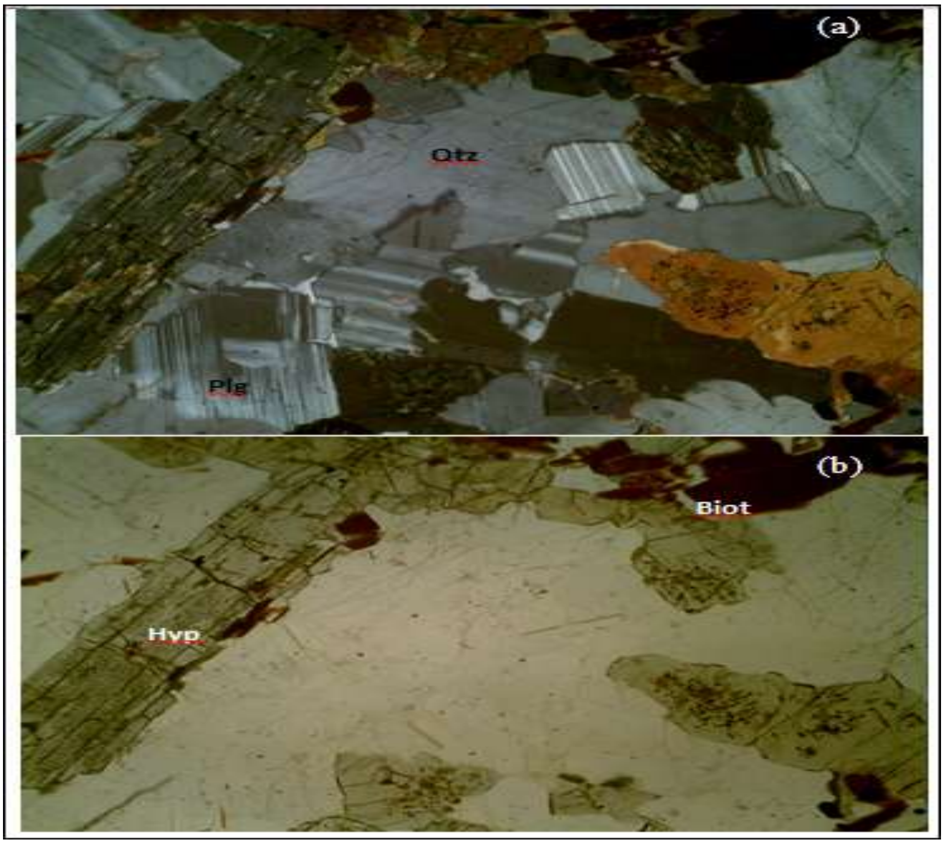


Plate 2- Sample 2 Photomicrograph of Sub Ophitic Texture between Quartz (Qtz) and Plagioclase (PLG) in Glimmerite under Cross Nicol and; (b) Photomicrograph of Hypersthene (Hyp) and Biotite (Biot) under Plane Polarized Light (PPL).

Plate 3- Sample 3 Photomicrograph of Sub Ophitic Texture between Quartz (Qtz) and Plagioclase (PLG) in Glimmerite under Cross Nicol and; (b) Photomicrograph of Hypersthene (Hyp), and Biotite (Biot) under Plane Polarized Light (PPL).

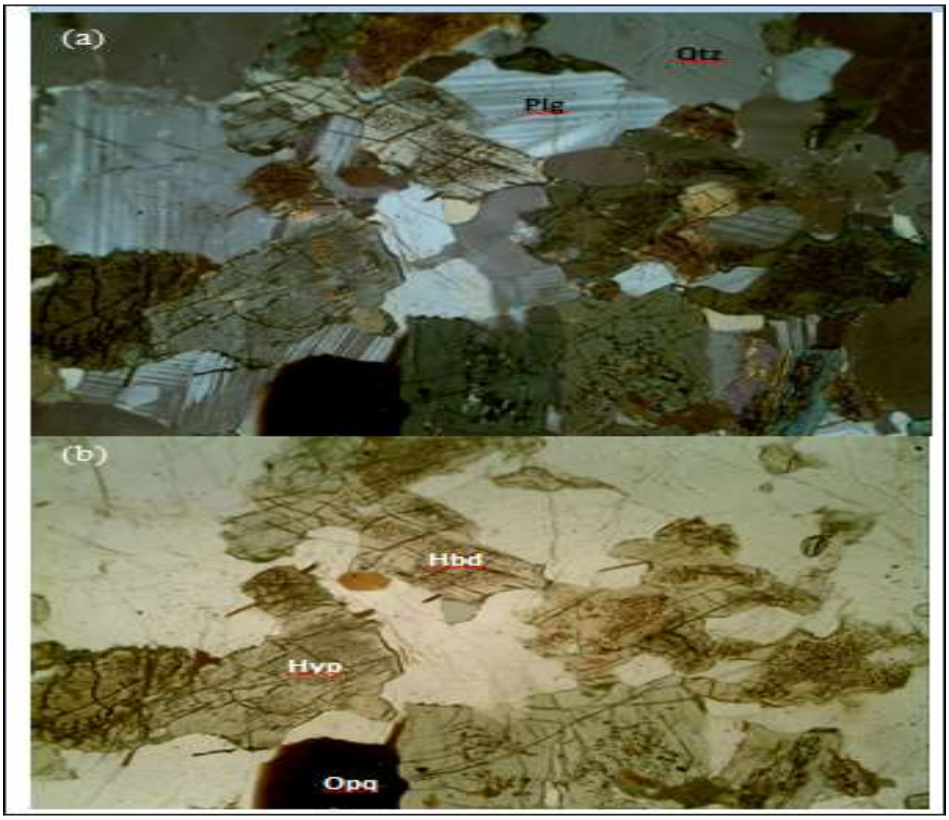


Plate 4- Sample 4 Photomicrograph of Albite Twinning between Quartz (Qtz) and Plagioclase (PLG) in Glimmerite under Cross Nicol and; (b) Photomicrograph of Hypersthene (Hyp), Hornblende (Hbd), Opaque (Opq) and Biotite (Biot) under Plane Polarized Light (PPL).

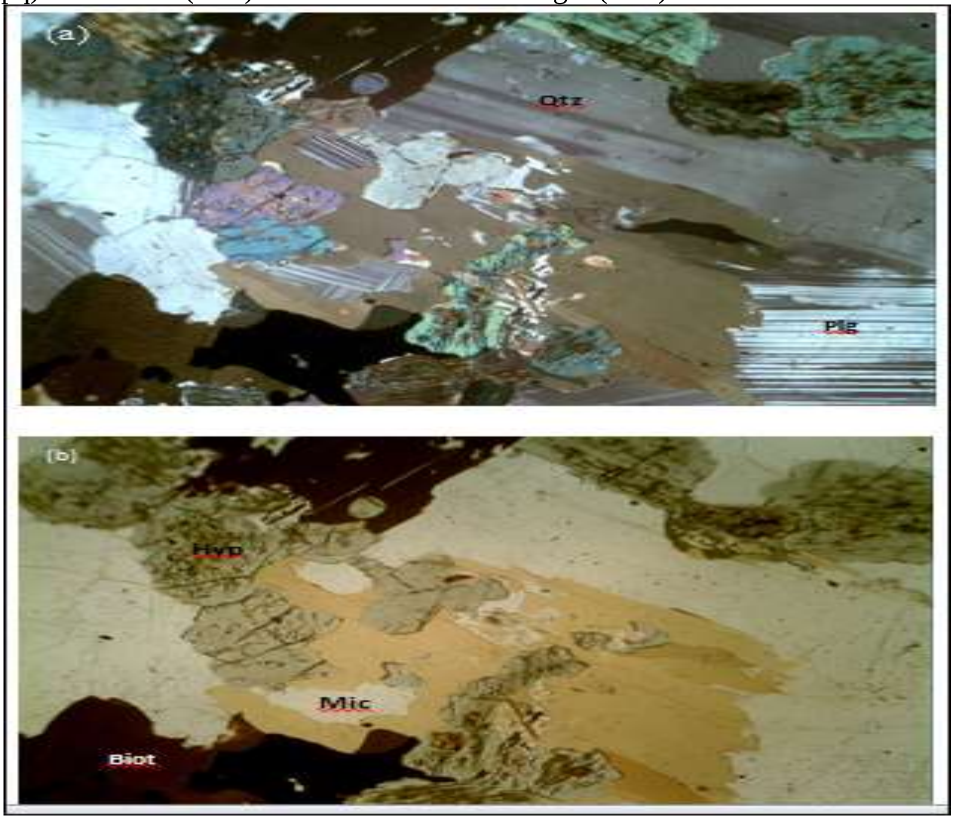


Plate 5- Sample 5 Photomicrograph of Albite Twinning between Quartz (Qtz) and Plagioclase (PLG) in Glimmerite under Cross Nicol and; (b) Photomicrograph of Hypersthene (Hyp), Microcline (Mic) and Biotite (Biot) under plane polarized light (PPL)

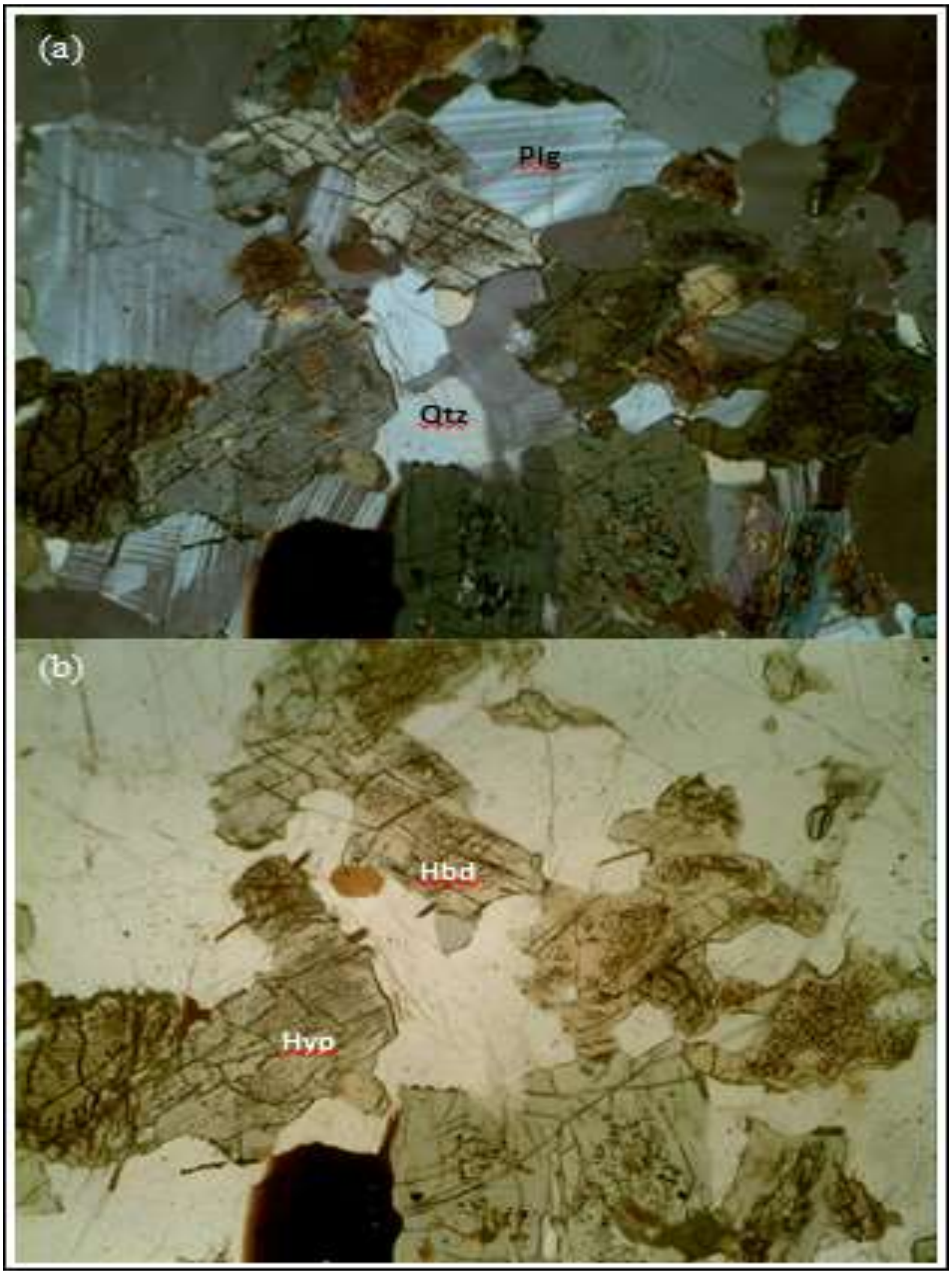


Plate 6- Sample 6 Photomicrograph of Albite Twinning between Quartz (Qtz) and Plagioclase (PLG) in Glimmerite under Cross Nicol and; (b) Photomicrograph of Hornblende (Hbd), Hypersthene (Hyp), under Plane Polarized Light (PPL).

Table 1- Key to Abbreviations of Mineral Constituents of the Photomicrographs of Rock Samples

S/N	KEY	Minerals
1	Qtz	Quartz
2	Plg	Plagioclase
3	Biot	Biotite
4	Hyp	Hyperstene
5	Hbd	Hornblende
6	Opq	Opaque
7	Mic	Microcline
8	Pyr	Pyroxene

Table 2- Estimate Modal Analysis of Mineral Composition of Samples.

MINERALS	**1**	**2**	**3**	**4**	**5**	**6**
	COMP.	**COMP.**	**COMP.**	**COMP.**	**COMP.**	**COMP.**
QUARTZ	17%	20%	17%	22%	11%	20%
MICROCLINE	-	-	-	-	8%	-
ORTHOCLASE	-	-	-	-	-	-
PLAGIOCLASE	26%	30%	33%	33%	30%	32%
MYRMEKITE	-	-	-	-	-	-
OPAQUE MINERALS	7%	6%	4%	4%	9%	6%
HORNBLENE	18%	12%	11%	14%	11%	11%
MUSCOVITE	-	-	-	-	-	-
OLIVINE	-	-	-	-	-	-
HYPERSTENE	16%	13%	19%	12%	16%	14%
PYROXINE	-	9%	-	7%	8%	9%
BIOTITE	16%	10%	16%	8%	7%	8%
TOTAL	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

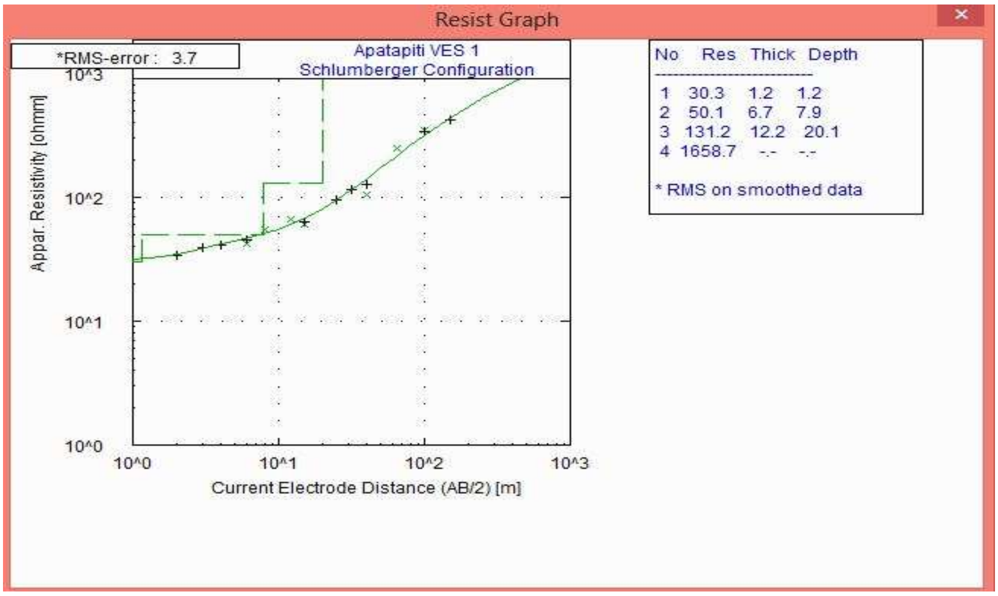
NOTE: COMP. = COMPOSITION

Table-3 provides a summary of the VES interpretation results from the partial curve matching. The maximum number of layers delineated by the curves is four. Three curve types were identified within the study area: AA, KH and HA. Typical curve types are shown in Figures-3 – 5. The predominant curve type in the study area is the KH curve type. This is indicative of the fact that the predominant geologic sequence in the area is the topsoil having a clayey content alternating with laterite which is underlying by weathered layer and fresh bedrock. Columnar sections were generated from the interpreted results (i.e. layer resistivity and thickness values) along the study area, which are shown in Figures-6 – 9.

Table 3- Summary of the VES Interpretation Results from Partial Matching of Curves.

VES	**ρ1 (Ω-m)**	**ρ2 (Ω-m)**	**ρ3 (Ω-m)**	**ρ4 (Ω-m)**	**h1 (m)**	**h2 (m)**	**h3 (m)**	**Curve Type**
1	30.3	50.1	131.2	1658.7	1.2	6.7	12.2	AA
2	15.7	46.2	31.6	125.3	0.7	1.6	5.9	KH
3	110.2	7.0	847.9	5844.0	0.4	0.8	2.5	HA
4	47.7	34.3	272.9	769.5	0.9	2.4	1.7	HA
5	44.7	90.3	134.2	237.4	1.7	4.7	5.2	AA
6	33.5	154.3	49.8	794.7	0.6	3.6	18.9	KH
7	20.5	103.7	437.8	2710.5	0.9	5.1	12.2	AA
8	96.6	104.0	269.1	481.4	0.5	6.9	13.9	AA
9	22.8	284.2	82.6	329.2	1.5	2.7	18.7	KH
10	51.9	36.1	736.5	16641.5	0.9	2.8	2.9	HA
11	44.6	206.9	73.7	4787.6	1.0	3.4	12.6	KH
12	39.5	161.0	40.9	1825	1.1	4.4	9.5	KH

NOTE: ρ= resistivity of the layers, h = thickness of the layers.

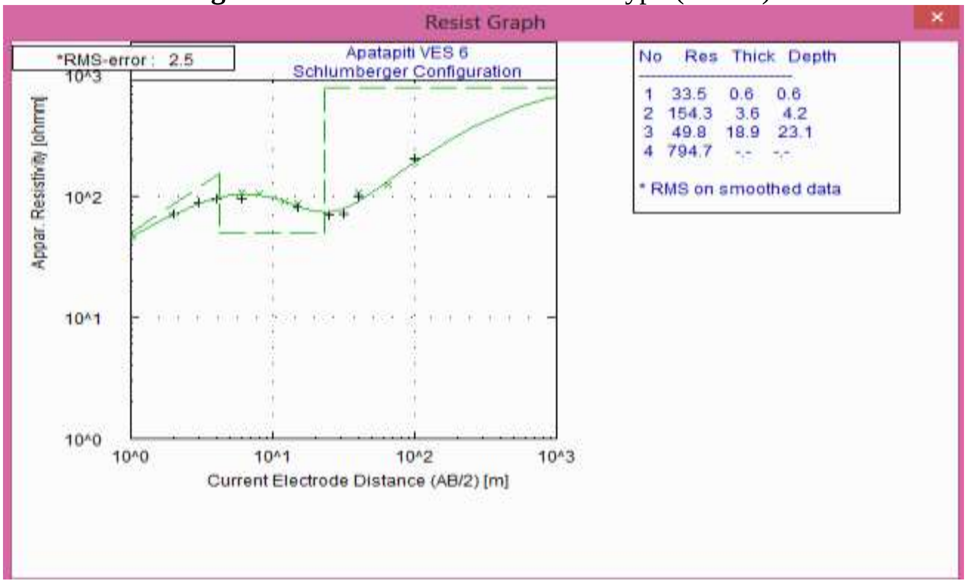


*RMS-error : 3.7

No	Res	Thick	Depth
1	30.3	1.2	1.2
2	50.1	6.7	7.9
3	131.2	12.2	20.1
4	1658.7	-.-	-.-

* RMS on smoothed data

Figure 3- Characteristic 'A' Curve-Type (VES 1).

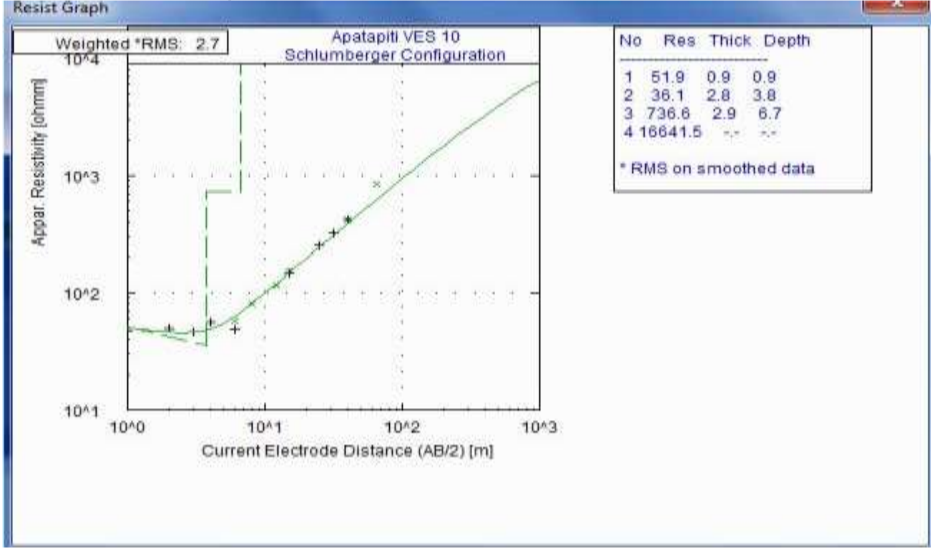


*RMS-error : 2.5

No	Res	Thick	Depth
1	33.5	0.6	0.6
2	154.3	3.6	4.2
3	49.8	18.9	23.1
4	794.7	-.-	-.-

* RMS on smoothed data

Figure 4- Classic 'KH' Curve-Type (VES 6).



Weighted *RMS: 2.7

No	Res	Thick	Depth
1	51.9	0.9	0.9
2	36.1	2.8	3.8
3	736.6	2.9	6.7
4	16641.5	-.-	-.-

* RMS on smoothed data

Figure 5- Typical 'HA' Curve-Type (VES 10)

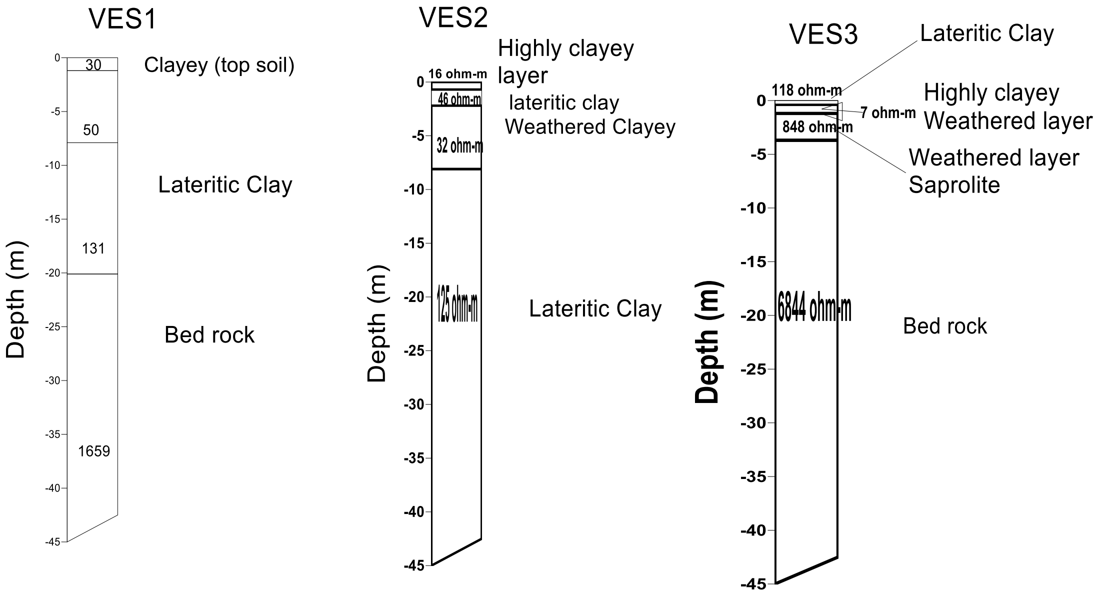


Figure 6- Columnar Section for VES 1 to VES 3 derived from field analyses (visual).

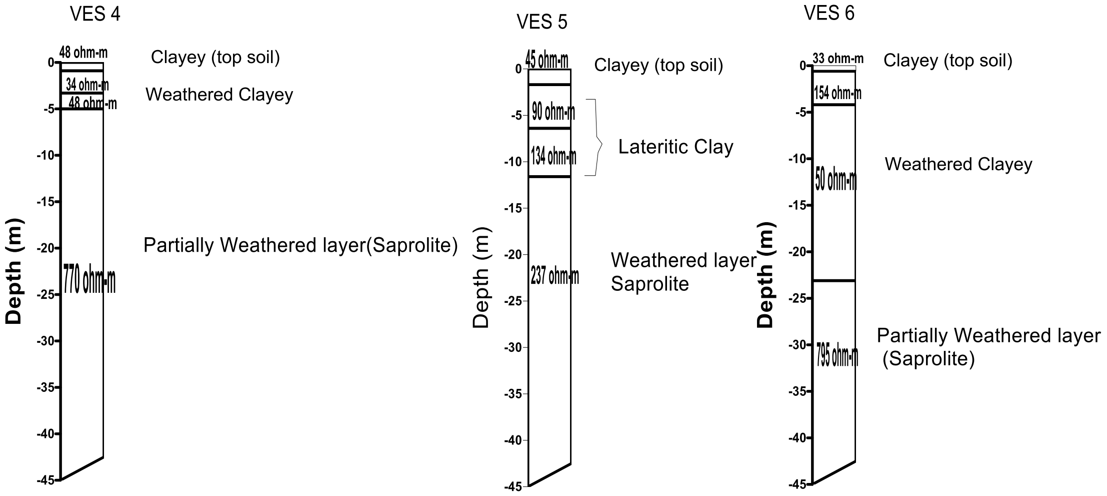


Figure 7- Columnar Section for VES 4 to VES 6.

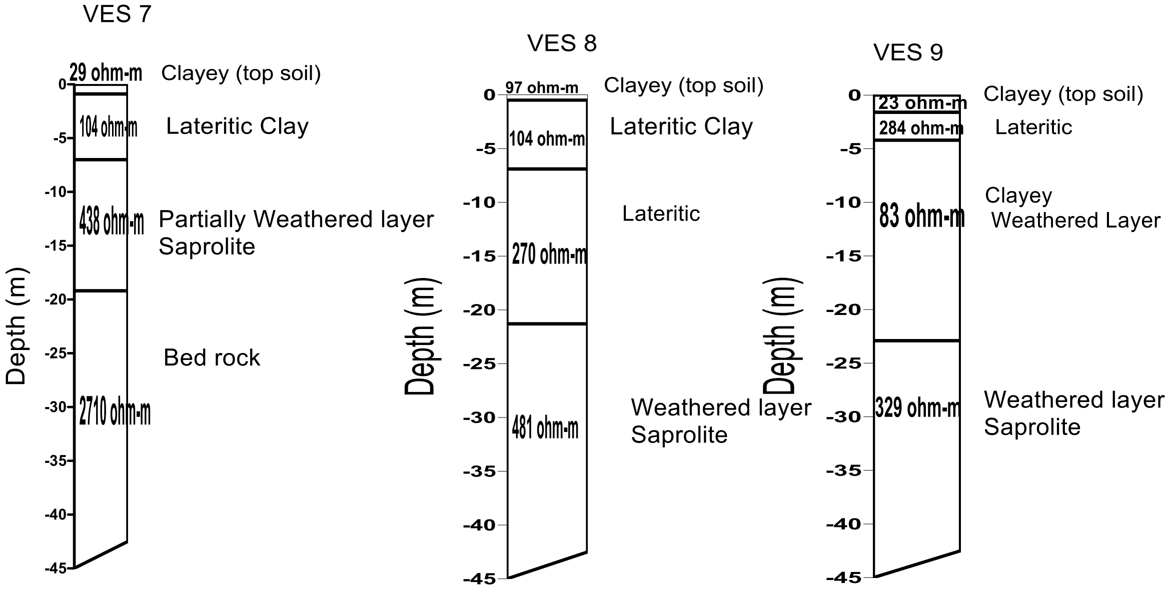


Figure 8- Columnar Section for VES 7 to VES 9 based on field analyses.

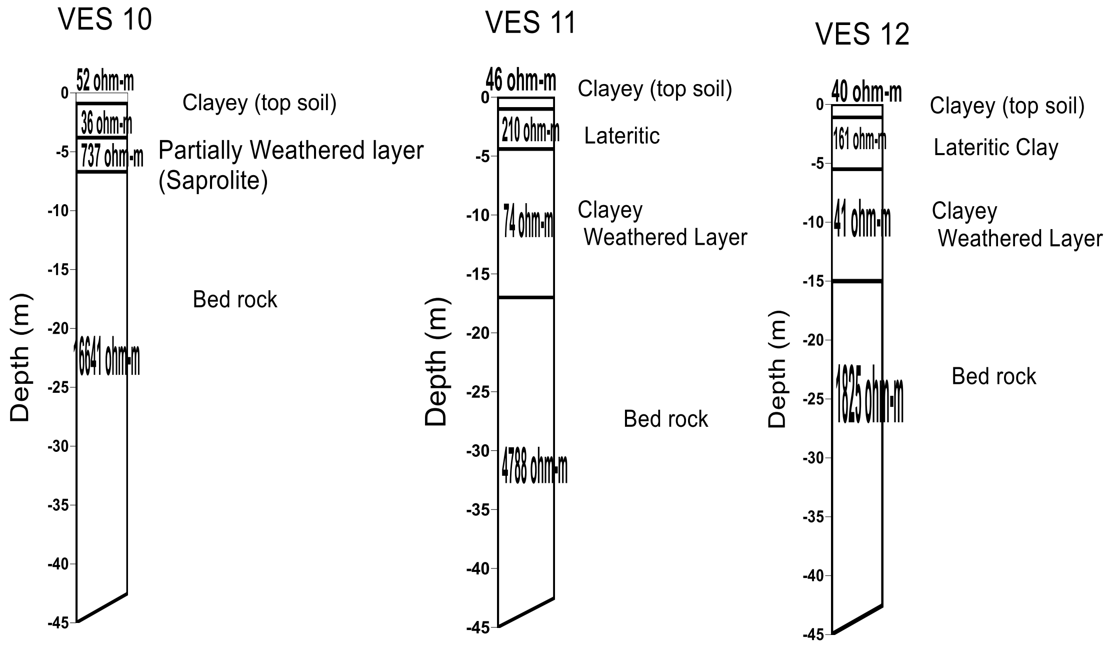


Figure 9- Columnar Section for VES 10 to VES 12 based on field analyses.

The correlation between the photomicrograph and the columnar sections of these VES points were carefully studied for detailed description. It was discovered that the topsoil is mostly clayey, which depicts the weathering of the feldspathic mineral composition of the rock in the area of study, with a thickness varying between 0.4 m and 2 m. This indicates a thin layer as a result of washing away of the top soil in the study area. The lateritic clay represents a low resistive layer next to the top soil with a thickness ranging from 0.8 to 7 m. VES 3, showing a highly clayey weathered layer which is a result of the deformation trait in the charnockitic rock of the environment [11]. The study area shows a reddish to brownish soil type related to the exchange of Iron II (Fe^{2+}) of the charnockite rocks, which turns the rock inter-phase in the environment reddish and aids weathering of rocks in the study area.

In the columnar section, low resistivity values are commonly encountered in layers 1 to 3 of the section below, which suggests a high percentage of clay in this environment or weathered zones along the sections. The thickness range is between 0.4 m and 8 m. The depth to bedrock in this environment is between 1 m and 25 m (overburden thickness).

The columnar sections also revealed the trend of deformation trait and weathering process in the environment, revealing a horizon that is suspected to be interbedded with laterite, sand, clays, and weathered saprolite. This could imply that the layers contain feldspathic minerals from their parent rock, while the lateritic-sands are quartz -bearing.

Figures 10 – 15 depict high composition of plagioclase minerals with very low resistivity values of the first and second layers. This may be a result of weathering, which depicts clayey composition as delineated in the columnar section of the environment which is majorly visible in Figure-11.

Materials which are a result of weathering of plagioclase minerals on the cross nicol show undulose extinction and distorted twinning. Thus, the photomicrograph serves as a good correlation with the columnar section in these entire samples.

Figures-10 – 15 also reveal the plane polarised view that acts as good visual aide to identify the presence of hyperstene and the hornblende mineral with several microcracks which resemble extinction traits, and can lead to a gradual disintegration of the parent rock. In view of this, it shows a good correlation between the photomicrograph and the columnar section along all the profiles. The mineral composition also depicts stressed materials as these microcracks can be seen in some of the minerals from both views.

The results of the electrical resistivity sounding analysis reflected that the weathering profiles displayed in the columnar sections reflect the petrographic properties of the rock samples at these locations. This is an indication that the physical and chemical characteristics of rocks wield a strong influence on the electrical responses of various rock types.

On the basis of mineral composition at location 1, the rocks are more resistant to weathering due to the presence of low plagioclase in the rock sample compared to samples from other locations which possess a higher percentage of plagioclase and hypersthene minerals, as shown in Figures-10 –15. This weathering condition could be favorable to hydrogeology only when there are interconnected fractures in the parent rocks (charnockite), otherwise the regolith thickness will serve as an aquiclude.

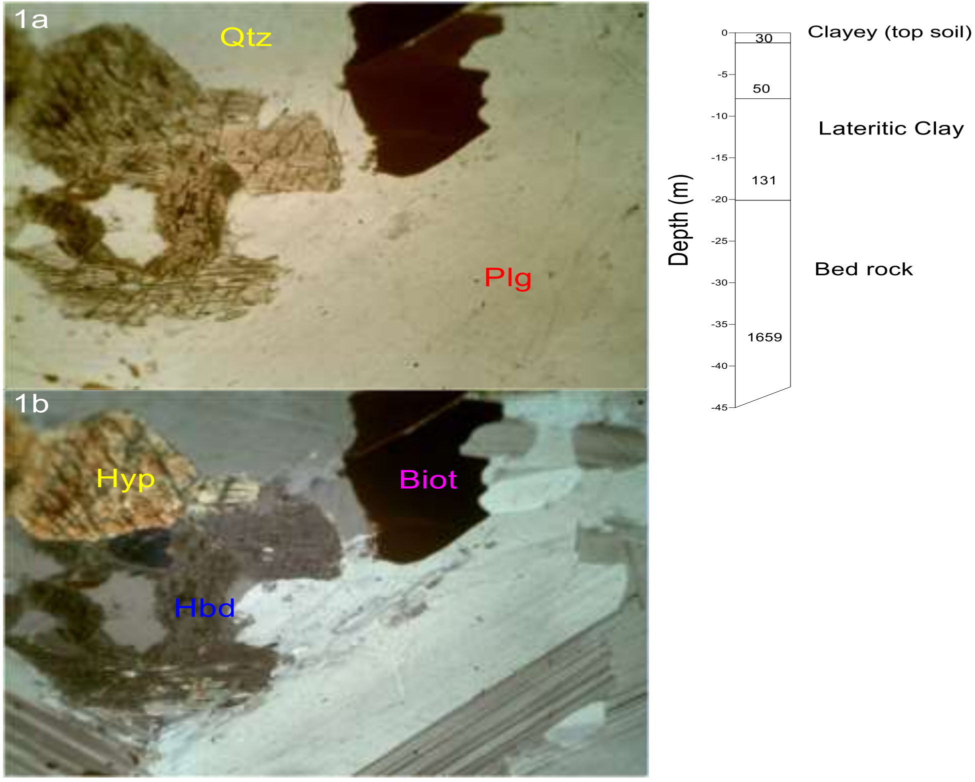


Figure 10- Correlation between Resistivity and Photomicrograph for Sample 1.

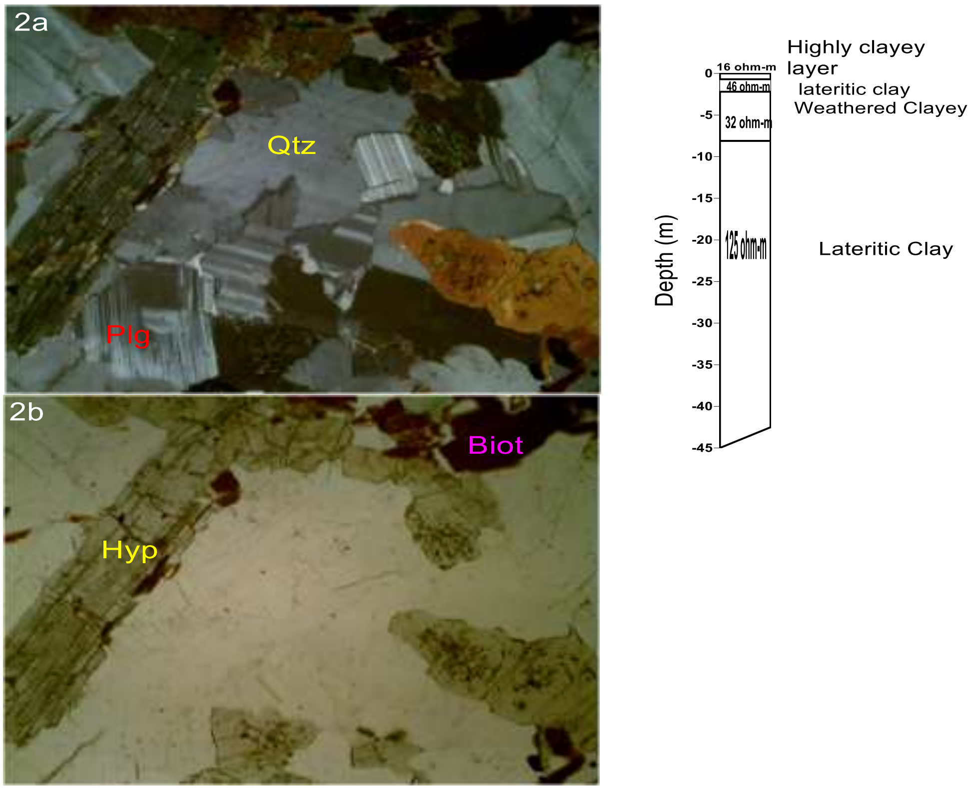


Figure 11- Correlation between Resistivity and Photomicrograph for Sample 2.

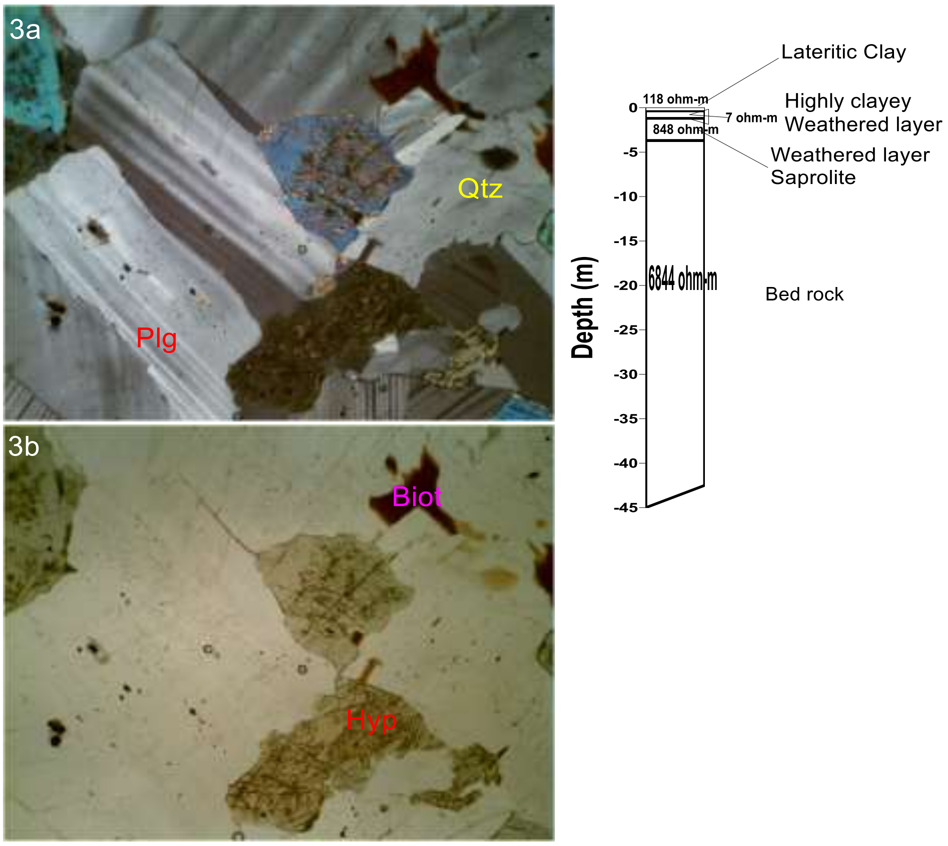


Figure 12- Correlation between Resistivity and Photomicrograph for Sample 3.

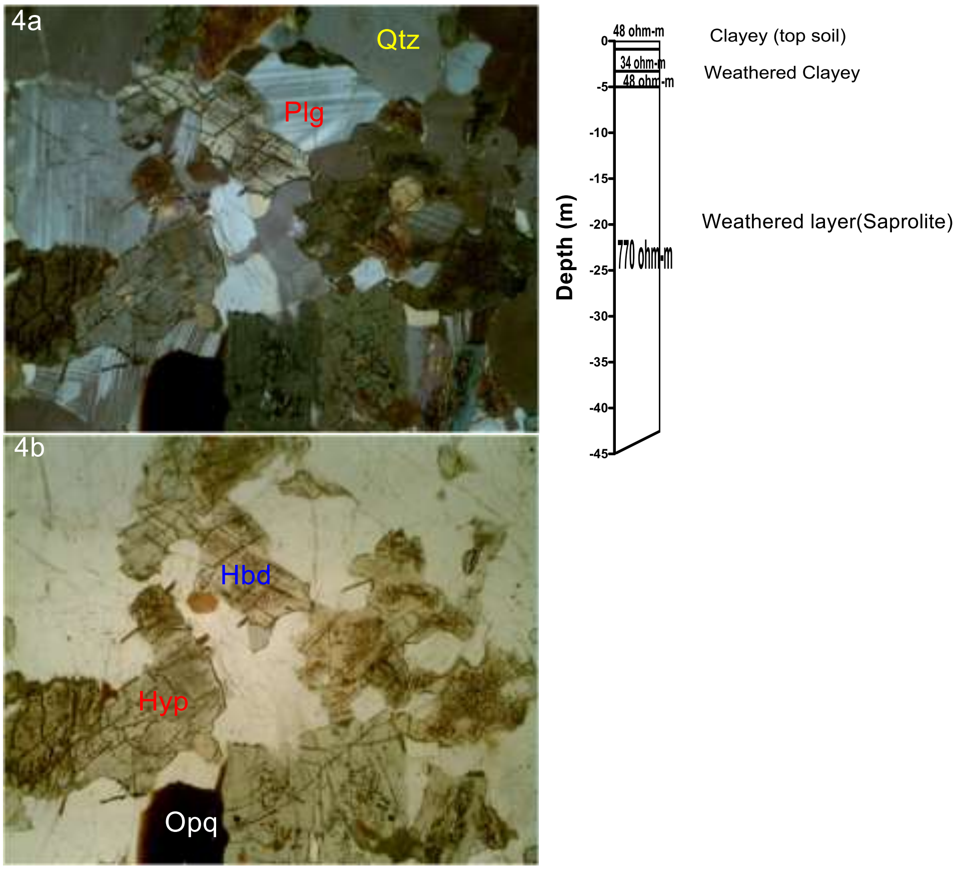


Figure 13- Correlation between Resistivity and Photomicrograph for Sample 4.

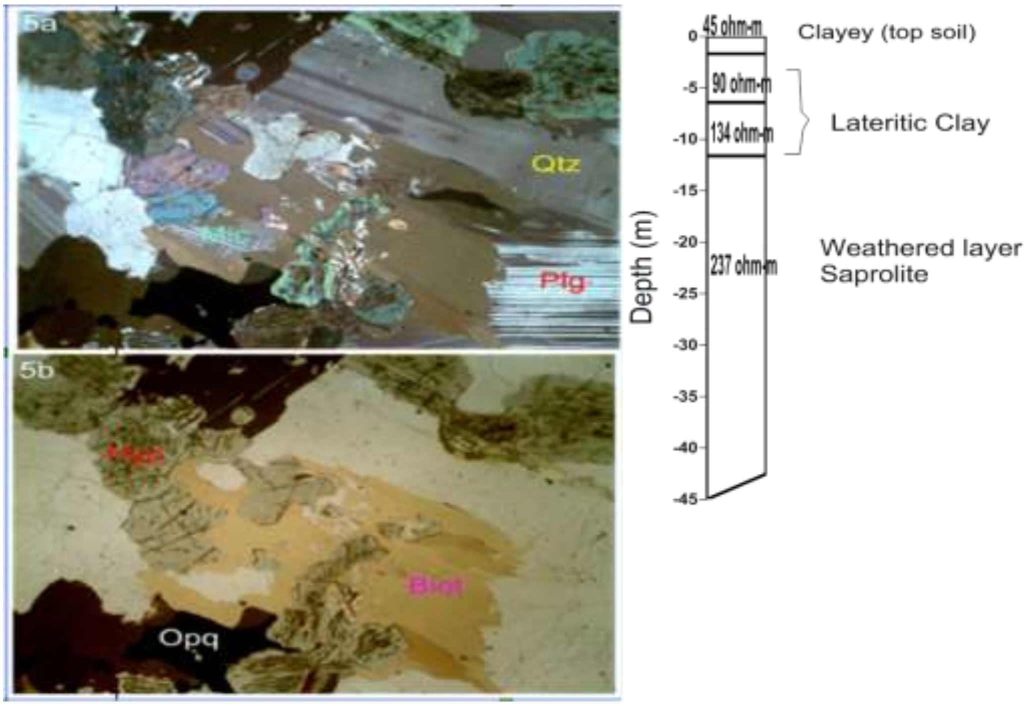


Figure 14- Correlation between Resistivity and Photomicrograph for Sample 5.

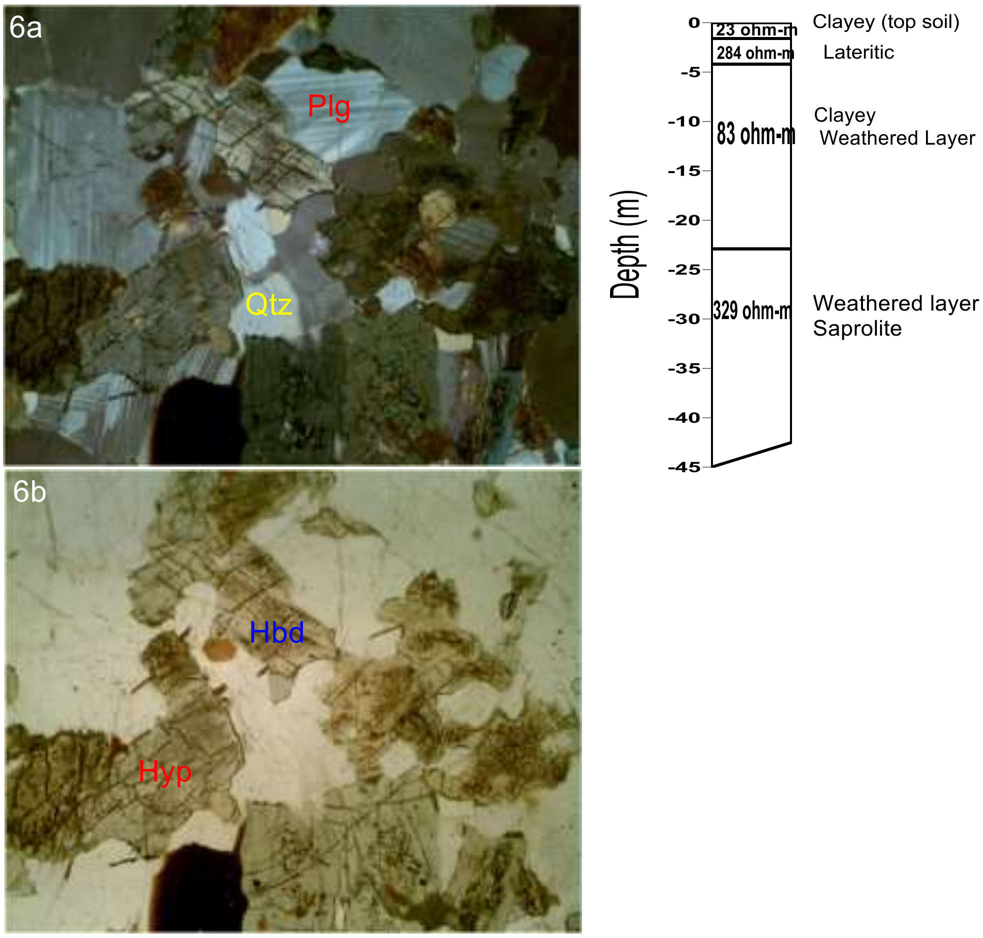


Figure 15- Correlation between Resistivity and Photomicrograph for Sample 6.

Geotechnical studies showed that clayey materials are poor materials for foundation studies and in construction of roads due to the swelling property that they possess. To propose a mega structure/

construct a road along this study area, it is advised that a proper geotechnical investigation is necessary in the study area.

5. Conclusion

A combined geophysical and petrographic laboratory investigation was carried out at Apatapiti Layout in Akure, Ondo State, Nigeria in order to correlate their results and attempt to assess their geotechnical and hydrogeological properties from these results. The geophysical analysis involving Vertical Electrical Sounding (VES) techniques via Schlumberger configuration. The petrographic analysis was performed on thin sections of rock samples taken at points of soundings.

The geophysical investigations revealed four geoelectric sequences within the study area, comprised of topsoil clayey, lateritic clay, partly weathered/fracture layer and bedrock. The topsoil is generally thin and basically composed of lateritic clay, weathered layer/ saprolite and clay, while the weathered layer is basically clay. The columnar section also revealed the undulating nature of the bedrock topography, with depth to bedrock ranging from 5 m to 25 m but averagely less than 15 m.

The petrographic results revealed that the soil has high modal estimation (31%) of plagioclase mineral composition, which is established as a weathering product of clay. This is followed by quartz and hypersthene minerals with 18% and 15%, respectively. The photomicrograph revealed undulose extinction and distorted twinning in plagioclase minerals, while almost all of the minerals exhibited micro cracks.

Therefore, hydrogeologically, the environment could be harnessed for favorable ground water condition only if thick regolith overlays fractured basement, otherwise, the geologic material in the environment will serve as a good aquiclude.

The geophysical results revealed a weathered layer which is unfit as a foundation material. If the foundation of the proposed building is to be hosted by this formation, its clayey nature has to be considered in the design of any engineering foundation, otherwise, the foundation may be better placed on the more competent bedrock.

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