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Research Article

INTEGRATION OF REMOTE SENSING AND GEOPHYSICAL METHODS FOR STRUCTURAL AND LITHOLOGICAL MAPPING IN A PART OF PRECAMBRIAN BASEMENT ROCKS, NORTHERN NIGERIA

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Abstract

Landsat 8 OLI data, Aeromagnetic data, and Radial Vertical Electrical Sounding (RVES) survey data were integrated to map lithology, delineate structures and their trends, and delineate possible mineralized zones in the area. Landsat 8 OLI data yielded a color composite image, and surface lineaments map of the area. The aeromagnetic maps were utilized to map lithology, and subsurface structures. A radial survey confirmed the fractures derived from the structural maps. Results classified the area into three geological units viz: migmatite, banded gneiss, and quartzite. The banded gneiss is the most deformed and contains series of structures that are significant for mineral and groundwater explorations. Clay alteration is the most dominant in the area, followed by iron oxide alterations. Lineament alignments are N-S, NNW-SSE, NNE-SSW, NE-SW, and E-W directions.

Keywords: Landsat 8 OLI, Aeromagnetic, Remote sensing, Radial Sounding, Lineament.

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1. INTRODUCTION

Lithological and structural mapping has become easier ever since the introduction of remote sensing techniques in GIS. Whilst GIS and Remote sensing techniques can never replace traditional field explorative geological mapping, they have provided geoscientists with invaluable techniques for improving the mapping process. The integration of other mapping methods such as geophysical methods has given synergy in the application of these techniques and has led to a reduction in error that may result from using a single technique. The use of remote sensing in mapping is very effective especially when an area is inaccessible, it saves time, reduces risk and it's cost-effective compared to other traditional mapping techniques [1]. Geophysics techniques add the value of subsurface confirmation to the surface observations obtained during surface mapping [2].

Airborne geophysics is also a valuable technique available to Earth scientists for investigating very large areas rapidly. The broad view of the Earth that the airborne geophysics perspective provides has been well recognized since the early days of balloon photography and military reconnaissance [3]. Compared to ground-based methods, the advantages of these methods are that very large areas and difficult terrain can be surveyed remotely in short periods thus making it very cost-effective. Out of the numerous airborne geophysical methods such as gravity, radiometry, magnetic, and electromagnetic aeromagnetic data has been adopted for this work.

The aeromagnetic survey is a common type of geophysical survey carried out using a magnetometer aboard and towed behind an aircraft allowing much larger areas of the Earth's surface to be covered quickly. The resulting magnetic anomaly map shows the spatial distribution and relative abundance of magnetic minerals (most commonly magnetite) in the upper levels of the crust. The magnetic map allows visualization of the geology and geological structures of the upper crust of the Earth. This is particularly helpful where bedrock is obscured by surface sand, soil, or water. Magnetic data are especially useful in structural and lithological mapping as it provides information such as structural trends in an area, lineaments direction, lithological boundary, etc. [4,5,6]. The subsurface geological signature obtained in the magnetic method is therefore aimed at complimenting the surface mappings results obtained from remote sensing results.

The electrical resistivity method is one of the geophysical investigation techniques which use the electrical properties of rock to differentiate the subsurface into geoelectrical layers. It can give an insight into the structures and lithological sections that are present beneath the earth's surface. The surface lineaments trends and structures could be signified in the form of resistivity anisotropy and geoelectrical equivalent layers could depict geological layer sequence. It could help to further investigate the results derived from these methods on the ground (i.e. ground trotting) [2].

This study aims at integrating GIS and RS with geophysical techniques to improve the map of the various lithology and structures present in the area, in other to map out the promising areas for mineral and groundwater exploration. This was accomplished by incorporating *Landsat 8 OLI* technique of remote sensing, aeromagnetic, and Radial vertical electrical sounding for structural and lithological mapping. It is believed that the findings of this research will provide a classy knowledge base through which further exploration researches could be built on.

1.2 Highlight on Geology of the study area

The area covers approximately 205 km^2, it is bordered by meridians 4^{o}35’ to 4^{o}45’ east and parallels 8^{o}20’ to 8^{o}30’ north. The topography of the area is characterized by hills, ridges, plains, and slopes to valleys with an elevation range of 380 m - 300 m. The area lies within the southwestern Precambrian basement complex of Nigeria (Figure 1) [7,8]. The basement complex of Nigeria is divided into three, The Northern, Southwestern, and Eastern basement complex. Overlying the gaps between the basement complex rocks are the Sedimentary basins of Nigeria.

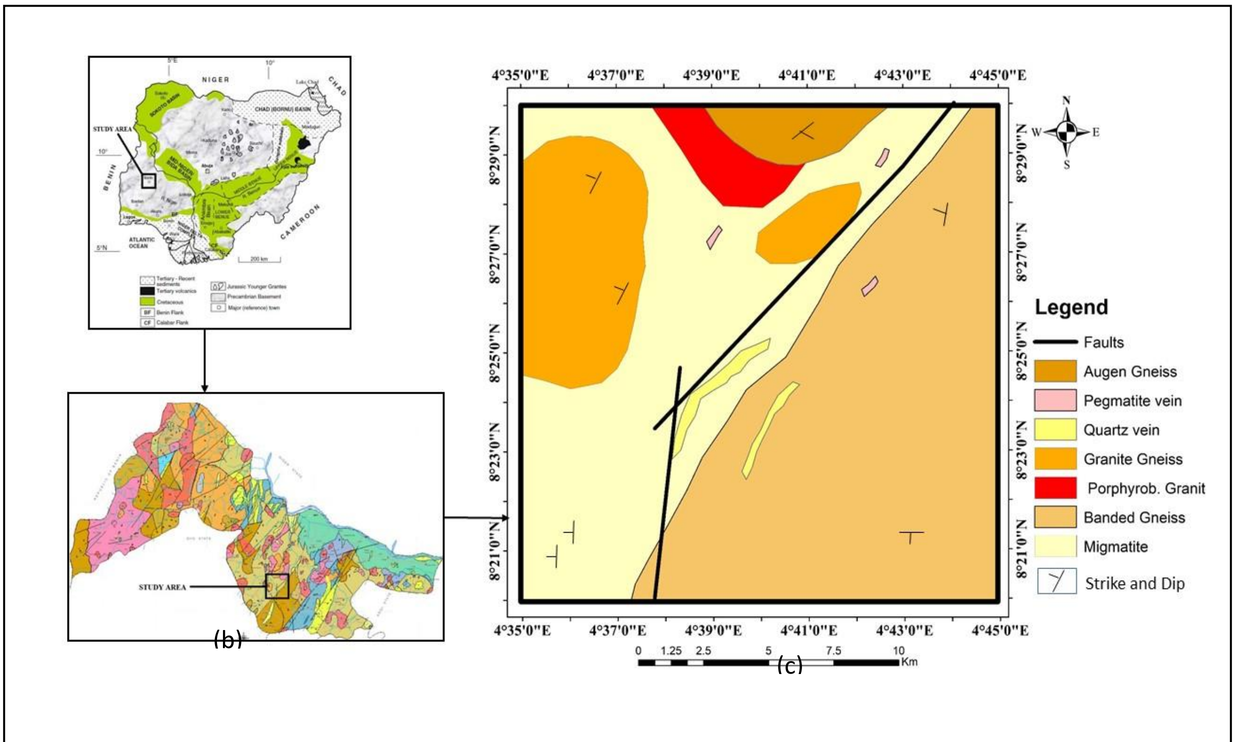

Fig.1. Geological map of the area of study: (a) Nigeria, (b) Kwara State, (c) Geology of the study area

The localized geology of the research area is that of the Southwestern basement complex terrain of Nigeria which consists of medium grade Metamorphic Rocks and low-grade

Metamorphic Rock [9]; granitic suites are found occasionally. The commonly found rocks (outcrops) in the area are migmatites, gneiss, granites, metasediments, amphibolites, and quartz, and pegmatite veins. The migmatite and gneiss rocks in the research area form presumably the oldest rocks in the area. They occupy the largest part of the area and are closely associated with quartzite. Pegmatite and quartz veins within the migmatite and the granite gneiss. They are of few millimeters to about a meter. They are concordant or discordant unmetamorphosed rock bodies cutting across foliation planes in the gneisses [10]. These crystalline basement rocks are older than 500 million years and contain a negligible amount of groundwater when not weathered or fractured [11]. However, significant aquifers may develop within those areas with thick weathered overburden and most importantly, fractured bedrock [12].

The area forms part of Ilorin geology. Porphyroblastic Gneiss is also part of the Basement Complex rocks of Ilorin and the environs. It is a metamorphic rock with planar or linear-shaped fabric, consisting of eye-like lentoid shapes (augen structure) which often results from the metamorphism of coarse-grained igneous rock and by the growth of porphyroblast. The palaeosome is usually schistose to gneissic and consists of biotite, muscovite, hornblende, and subordinate quartz, plagioclase, and microcline. Granite Gneiss in Ilorin has granitic composition and some foliations. They are generally well exposed, usually occurring as isolated domes and low-lying ridges often strewn with boulders. They have generally been exposed around the Offa garage, Danial, and basin area. They can also be found on the University of Ilorin campus. They cover about 20% of the Ilorin area and occur as isolated domes and low ridges. Locally, there may be a development of microcline porphyroblasts, usually aligned parallel to foliation. There is often a tendency towards digestion or obliteration of an original layering, an indication that these gneisses might have a metasedimentary origin [9]. The mineral compositions are mainly microcline, and quartz, with some plagioclase (oligoclase), biotite, muscovite, hornblende, sphene, and apatite. Quartzites also occur within the area of research, they are formed as a result of the metamorphism of sandstone. The constituent grains recrystallized and developed an interlocked mosaic texture with little or no trace of cementation. The essential mineral components are predominantly quartz and other minerals include muscovite, opaque minerals, and occasional garnet [9]. Pegmatite and quartz vein-filled fractures in the migmatite and quartzite of Ilorin metropolis are generally NS and NW–SE while those in the granite gneiss are NS and NE–SW [10].

Further, NNE –SSW foliations which have been folded to form the major folds are also present in the research area. The crystalline basement rock in the area must have been affected by both Eburnean Orogenies. The Eburnean Orogeny caused the magnetization and metamorphism of the ancient metasediment while the Pan Africa orogeny produced the intrusion of the granitic materials [9].

2. MATERIALS AND METHODS

In addition to the preliminary geological mapping of the area, other materials employed in this study are the Topographical map of Ilorin N.W. Sheet 223 sourced from Kwara State Government, ASTER Digital Elevation Model (ASTGTM2_N08E004), and Landsat 8 OLI scenes of Kwara state (LC08_L1TP_190054_20181225_20190129) sourced from usgs.gov, a geological map of Kwara state and an aeromagnetic data of Ilorin sheet 223 N.W. sourced from Nigeria Geological Survey Agency [13]. ArcGIS 10.8 software was utilized to digitize maps while ENVI 5.1 software was employed for Landsat 8 image processing, Aeromagnetic data were processed using *Oasis Montaj* software by *Geosoft* while PCI Geomatica and Georose software were deployed for Automatic Lineament extraction and plotting of the orientation of extracted lineaments respectively.

For a detailed structural and lithological mapping, surface lineaments were extracted from a processed Landsat 8 data of the area of study using an automatic lineament extraction tool in PCI Geomatica. Subsurface lineaments were extracted from the first vertical derivative map of Ilorin sheet 223 using *Oasis montaj* software from Geosoft, the lines were later exported to ArcGIS where it was converted into CAD format for further processing in Rockworks and Georose. Digital Elevation Model map was draped over geology map of the area of study for a better understanding of lithology across the area as well as geomorphologic information of the area. The Colour composite of Landsat 8 bands was used for image classification while band ratios and principal component analysis were used to map hydrothermal alteration zones across the area of study.

Landsat 8 data were processed further using ENVI 5.1. Atmospheric correction was applied to the Landsat 8 scenes using the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercube (FLAASH) algorithm [14,15]. The FLAASH algorithm was implemented using the Sub-Arctic Summer (SAS) atmospheric and the Maritime aerosol models [16]. During the atmospheric correction, raw radiance data from the imaging spectrometer were re-scaled to reflectance data. Properties and uses of the band of a Landsat 8 were referred to as Operational land imager (OLI) and thermal infrared sensor (TIRS) band designations table of

[17]. The deep-blue band (band 1), the panchromatic band (band 8), and the cirrus cloud band (band 9) of Landsat 8 were not used in this study. Color composite images were produced based on known spectral properties of rocks and alteration minerals concerning the selected spectral bands. Bands 4 3 2 were used to produce true color composite while bands 541 were used to produced false-color composite images of Unilorin and environs for lithological mapping. Band ratio indices were developed and implemented to Landsat-8 spectral bands for mapping poorly exposed lithological units, geological structures, and alteration mineral assemblages. Spectral-band ratio indices were then calculated to map spectral signatures of iron oxide/hydroxide minerals, OH-bearing and Fe, and Mg-O-H lithological units within the area of study.

For mapping the abundance of iron oxide/hydroxide mineral groups in the rocks' surfaces using Landsat-8 bands, two-band ratios were developed based on the laboratory spectra of the minerals [18; 19; 20]. Hematite, jarosite, goethite, and limonite tend to have strong absorption features in VNIR (0.4–1.1 μm), coinciding with bands 2, 3, 4 and 5 of Landsat-8 and high reflectance in SWIR (1.56 μm–1.70 μm), coinciding with band 6 of Landsat-8 [21]. Therefore, Band ratio 4/2 was used to map iron oxide, mineral groups. SWIR bands of Landsat-8 were used for the identification of Hydroxyl-bearing (Al-OH and Fe, Mg-OH) mineral groups within the area of study. Clay minerals contain spectral absorption features in 2.1–2.4 μm and reflectance in 1.55–1.75 μm, which coincide with band 7 (2.11–2.29 μm) and band 6 (1.57–1.65 μm) of Landsat-8 [21]. Therefore, ratios 6 on 7 have been used to map Hydroxyl bearing mineral group in this study. For the ferromagnesium (Fe, Mg-OH) group of minerals, bands 5 and 6 of Landsat 8 were used because of the high absorption characteristics of this group in bands 5 and low absorption features in band 6. Principal Component Analysis (PCA) was employed for hydrothermal alteration mapping. Alteration zones signify the presence of ore bodies in an area and give the nearest location for the gold deposit. Most of the alteration types associated with gold deposits are sericitization, oxidation, silicification, and carbonization, and ammoniation [22].

High-resolution aeromagnetic data of Ilorin sheet 223 was obtained from Nigeria Geological Survey Agency [13]. The data were acquired between the years 2004 and 2009 by Fugro Airborne Survey Limited and presents a magnetic total field at a data recording interval of 0.1s using a 3x-Scintrex CS3 Cesium Vapour magnetometer and at a flight height of 200 m. For structural and lithologic mapping, aeromagnetic data of the present area of study was windowed out from Ilorin sheet 223, the windowed map was gridded and transformed using Fast Fourier Transform (FFT). Residual Magnetic intensity map of the area was reduced to pole for lithology mapping while the first vertical derivative filter was used for structural mapping. The ability to reveal near-surface structures such as faults, folds, etc. makes aeromagnetic data suitable for this purpose.

Schlumberger sounding array (Figure 2) was adopted in this study. Apparent resistivity resulting from the current and potential difference flowing in the heterogeneous subsurface rocks was recorded. This provided subsurface information as a reflection of the surface responses obtained from geology and Landsat signals.

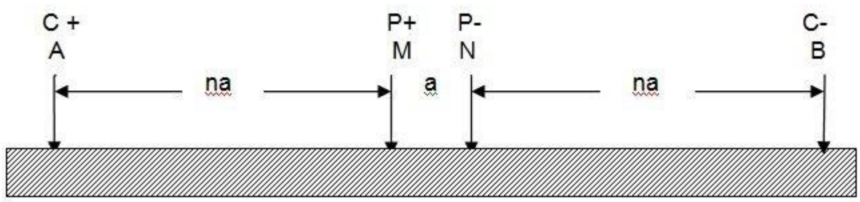

Fig.2. Schlumberger array adopted

Using Ohm’s law;

$$V = \frac{I\rho L}{A} \quad (1)$$

Apparent resistivity could be expressed as

$$\rho_a = GR \quad (2)$$

Where G is the geometric factor, derivable from the electrode configuration used and R is the resistance.

A total of 9 Vertical Electrical Radial Sounding (VERS) points were used to confirm the presence of anisotropy, signifying fracture within the area.

3. RESULTS

3.1 Geological mapping

Geological mapping shows that the research area is mostly dominated by igneous and metamorphic rocks such as Migmatite, Granite Gneiss, Banded Gneiss, Augen Gneiss, and Porphyroblastic Granite. Minor rocks in the area are the pegmatite vein and quartz vein. Some of the rocks and observed structures are shown in Figure 3.

Fig.3. (A). N-S trending foliation fabric in Granite Gneiss in the research area (B). N-S trending joints and fractures around Ilorin metropolis, (C). E-W trending pegmatite vein in banded gneiss around Fufu, (D). N-S trending quartz vein in granite gneiss along University of Ilorin Road, (E). Augen gneiss within the University of Ilorin Campus, (F). N-S plunging axial plane of an open fold on granite gneiss cut across by an E-W trending joint along Jimba-Oja road (the tip of the pen points to the North).

3.2 Aeromagnetic survey

A reduction to the pole, RTP filter (2D-FFT), was applied to the Residual Magnetic Intensity (RMI) grid using the average parameters of inclination of -8.85^o and declination of -1.43^o for the area of study. This is done to locate the observed magnetic anomalies directly over the magnetic source bodies, and to remove the influence of magnetic latitude on the residual anomalies as Murphy [23] recommended, to obtain an RTP map (Figure 4). Figure 5 is its First Vertical Derivative (FVD) map, projected upward to 100 m height to reduce the effect of manmade features that could mask the expected outcome. The extracted subsurface lineaments from the FVD process are shown in Figure 6 while the orientation of these lines is shown using the rose diagram in Figure 7.

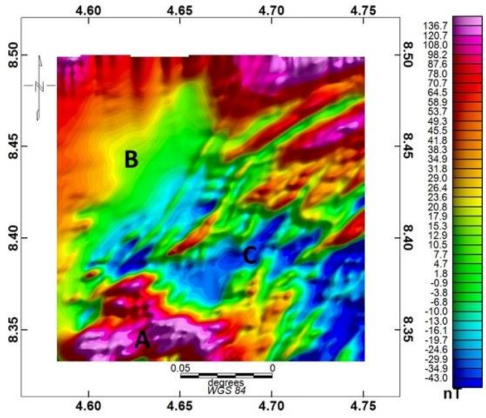

Fig.4. RTP map of the research area

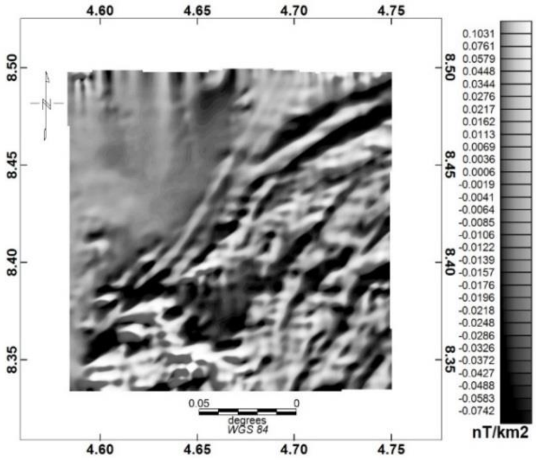

Fig.5. FVD map continued upward to 100 m

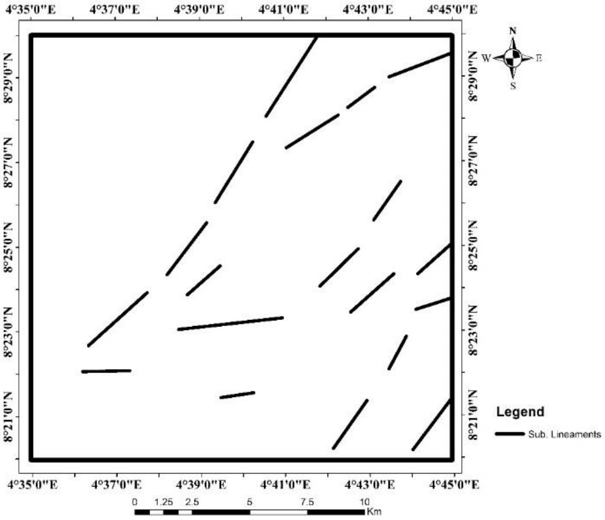

Fig.6. Vectorized lineaments from FVD

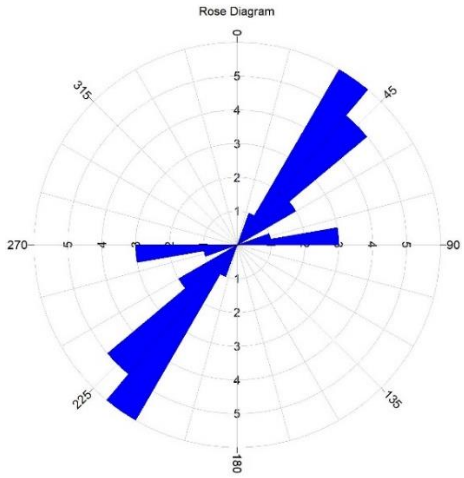

Fig.7. Rosette plot of the orientation of subsurface lineaments in the research area

Landsat 8 data of the area were processed to complement results derived from the aeromagnetic. This was done, by the creation of a false colour composite map, band ratio approach, and lineament analysis, to map the identified structures for mineralogical components using band ratios, zones of possible hydrothermal alteration using principal component analysis as well as lineaments present. Figure 8 shows the false colour composite (FCC) map of the area of study. Band ratio was used to detect the various types of alterations that are taking place in the area of study and is shown in Figure 9. Principal Component Analysis (PCA) was used to further probe the alterations taking place in the research area and is shown in Figure 10. The surface lineaments that are present in the research area were extracted and shown in Figure 11 while a rosette plot of the orientation of these lineaments is also displayed in Figure 12. Both the surface lines and subsurface lines are combined and superimposed on the geological map for updating the geological map with structures deduced from both magnetic and remote sensing methods (Figure 13).

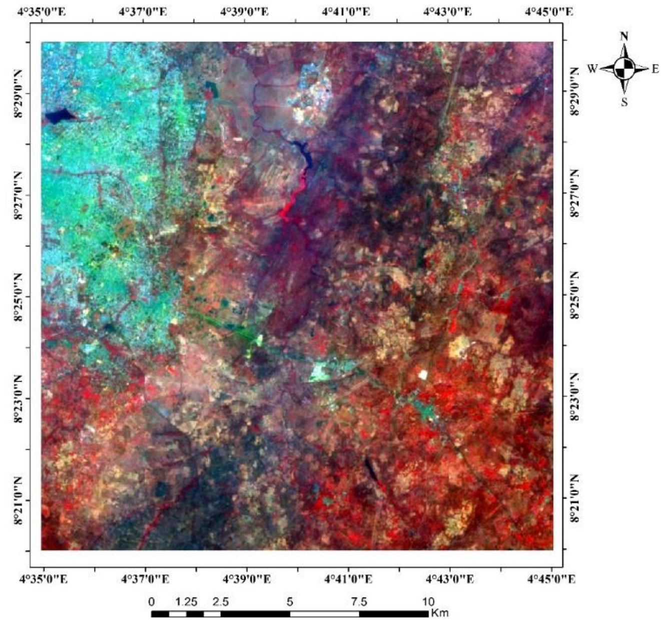

Fig.8. False colour composite (FCC) map of the research area

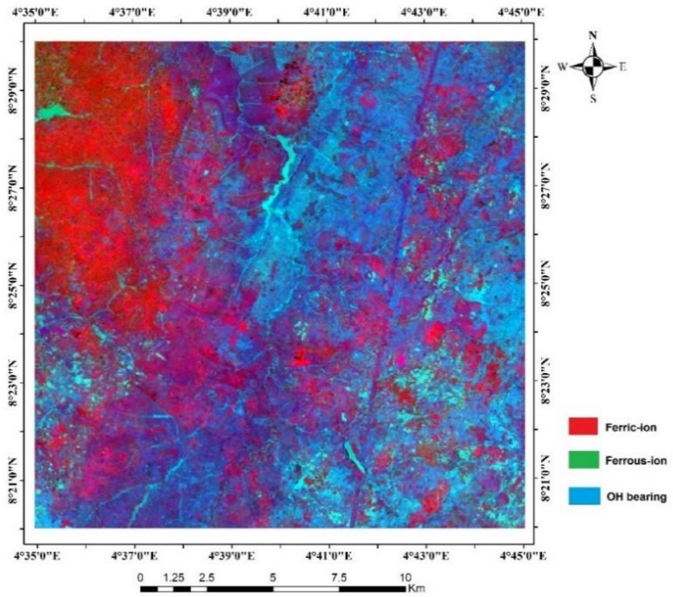

Fig.9. Band ratio map of the research area (4/2 ferric ion. 5/6 ferrous ion, and 6/7 for OH bearing alterations)

The yellow colour on the map represents zones of clay alteration while blue to cyan represent zones of iron oxide alteration. The bright coloured areas are the hydrothermal alteration zones (Figure 10).

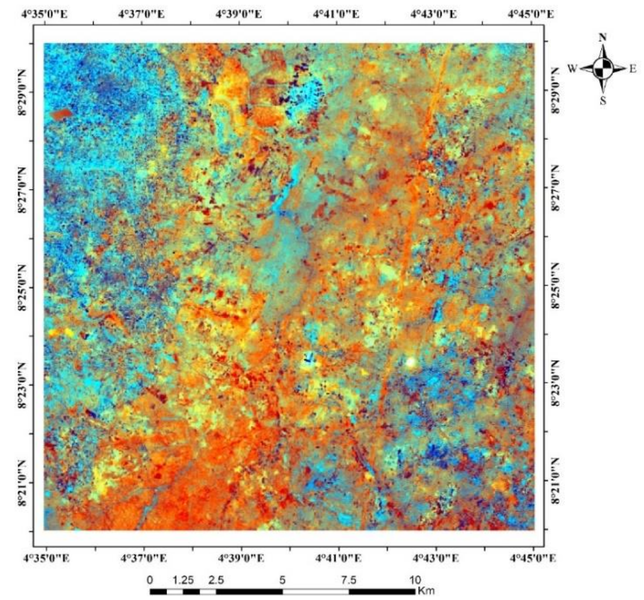

Fig.10. Principal Component Analysis (PCA) map of the research area.

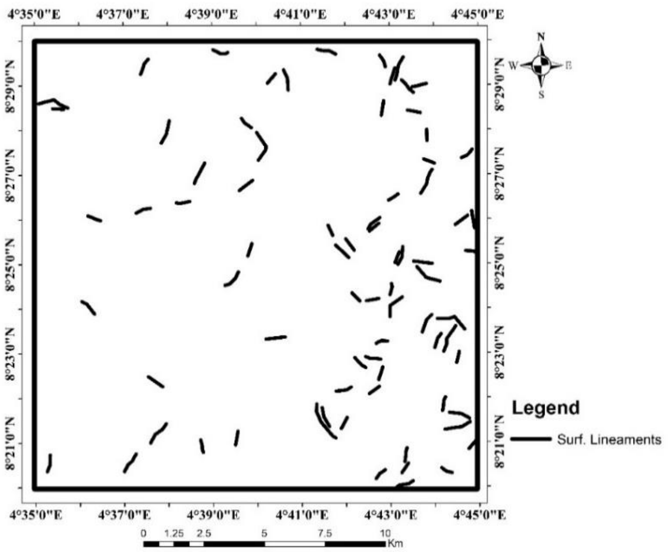

Fig.11. Extracted surface lineaments (from band 7 of Landsat 8 data) of the research area

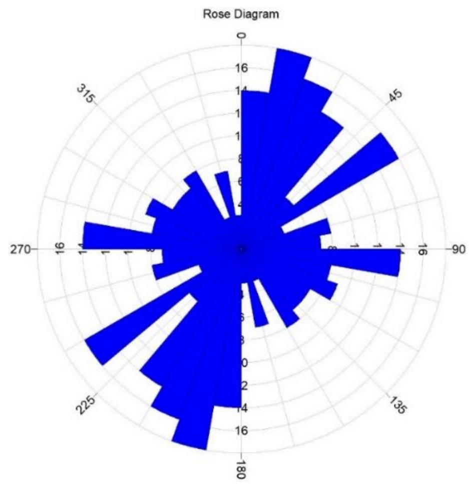

Fig.12. Rosette plot of the orientation of the surface lineaments

Resistivity radial soundings revealed depth-dependent anisotropic variation, at depths classified as shallow, intermediate, and great depths (Table 1).

Table 1. The trend of subsurface anisotropies

STATION	SHALLOW DEPTH	INTERMEDIATE DEPTH	GREAT DEPTH
1	NE – SW	NE - SW	NW – SE
2	NE - SW	E - W	E – W
3	NE – SW	NE - SW	NE – SW

Table 1 shows a greater concentration of anisotropies at shallow and intermediate depths. It is further deduced from the table that the directions of anisotropies follow the major directions of faulting in the basement areas (NW - SE, NE - SW, and E-W) as shown by [9].

The lithologic contact between the migmatite and banded gneiss was been better viewed and it was seen that the quartz schist is also aligned in the direction the contact is aligned to. It was also observed that the banded gneiss terrain is more deformed than the migmatite terrain (Figure 13).

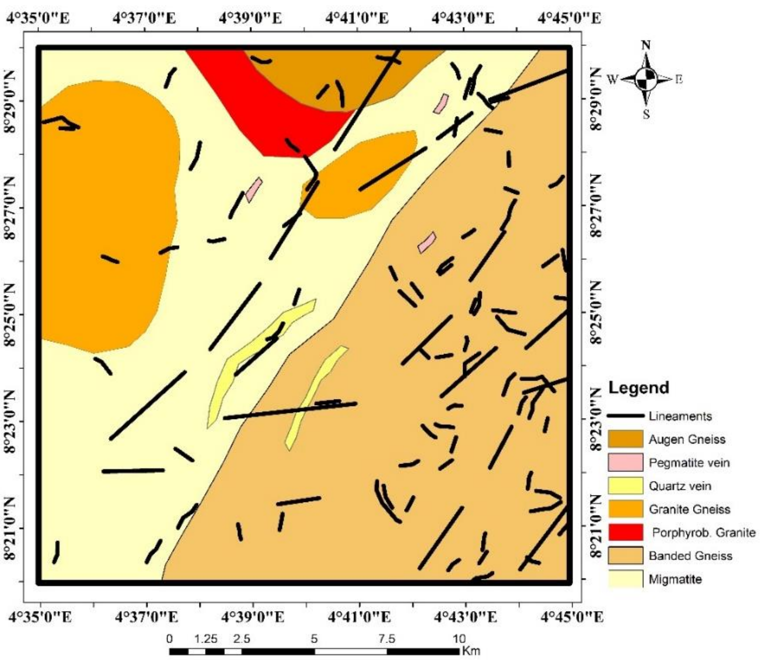

Fig.13. Geological map of the area of study with extracted lineaments

Radial vertical electrical sounding (RVES) was employed to further confirm the subsurface geometry of the observed structures. RVES results depict the effect of resistivity anisotropy, as the values of resistivity are directional dependent. It also reveals that the curves are made up of three layers of H-type (that is $\rho_1>\rho_2<\rho_3$), where ρ_1, ρ_2, ρ_3 are the resistivity of first, second and third layer respectively. The layers and their thickness range are identified as topsoil (0.5-1.1 m), weathered basement (1.0-5.0), and fresh basement. The common anisotropic directions are NW-SE, NE-SW, and E-W, which followed the major directions of faulting in the basement terrain of Nigeria as reported by [24]. This equally agreed with the aeromagnetic and remote sensing results (Figures 7 and 12).

4. DISCUSSION

Detailed geological mapping revealed that augen gneisses, banded gneiss, and porphyroblastic granite, and quartz vein are the dominant rock types within the University of Ilorin Campus. Migmatite, granite gneiss, banded gneiss, and pegmatite vein occur within the surrounding localities. These rocks have undergone various episodes of deformations which is typical of rocks within the basement complex terrain of Nigeria. This is responsible for the various joints and fractures that are present in these rocks. Structurally, the orientation of the pegmatite veins in the research area is mostly in the NE-SW directions while the quartz veins are aligned in the N-S and E-W directions. The general orientation of joints in the area of study is the E-W, N-S, and NE-SW direction, while the foliations within the granites, gneisses, and migmatites are in the N-S and E-W directions. Also, fracture distributions are strictly in the N-S and E-W and NE-SE, NNW-SSE directions (Figure 3). The availability of structures such as joints, faults, fractures, and folds are prerequisites for groundwater accumulation within basement complex rocks. This signals the ability of rocks within the area of study to have the potentials to house groundwater.

Magnetic intensity in the area, shown in Figure 4, ranged from -43.0 to 136.7 nT; -43 to 7 nT for low magnetic intensity (C), 7 to 30 nT for moderate magnetic intensity (B) and 30 – 137 nT for high magnetic intensity (A). A high magnetic signature, considered to be due to the presence of rocks containing a high proportion of magnetic minerals such as migmatite, gneiss, granodiorite, etc, mostly occurs around the eastern part. Moderate magnetic anomalies occur mostly around the NW in the area, covered by rocks such as granite and granite gneiss. Low magnetic signatures are seen mostly from the central to the SE part in the area. This could be produced by materials such as sediments, alluvial sands, quartzite, etc. Thus, these varying magnetic responses signified lithology and tectonic activities that have culminated into the geological structures such as folds, faults, and fractures observed in the area. Further, linear geological structures associated with the various volcanic rock types are observed as moderately low and low magnetic signatures. The negative magnetic anomaly regions displayed in deep blue coloration are potential hydrothermal zones. They represent zones of magnetic discontinuity which may be due to the influx of hot fluid into the country-rock. Mineral exploration efforts could be concentrated within these areas. FVD map (Figure 5) displays lithological contacts, folds, and faults which are likely produced by several episodes of deformations within the basement complex of Nigeria. The displayed lineaments (Figure 6) depict geologic structures such as fractures, faults, folds, etc. Lineaments are more concentrated on the banded gneiss terrain (SE) than the migmatite terrain (NW). The general orientation of the lineaments in the area, shown in Fi.g 7, is mainly in the NE-SW and NW-SE trend which is attributable to Pan African orogeny (600 Ma) and Kibaran Orogenic (1100 Ma) cycle of deformation [6,25,26,27].

On the FCC map (Figure 8) red colour depicting areas of high vegetation cover concentrated at the SE, blue to cyan representing built-up areas falls mostly within the Ilorin metropolis, the black colour representing water bodies such as Asa dam can be seen at the NW, and brown colour standing for the exposed rocks/outcrops while yellow represents open/virgin land scattered in the area. The red colour depicting iron oxide alterations on the band ratio map (Figure 9) shows a high concentration of iron oxide at the NW part of the area and few portions scattered toward the east. Gold exploration is likely to be found in regions of iron oxide alteration. Ferrous minerals (green) are seen in patches at the east while hydroxyl (OH) bearing materials (blue) that could be due to clay alteration dominates the study area. On the principal component analysis (PCA) the western part of the area (Figure 10) shows iron oxide alterations while the central and eastern part of the study area shows clay alteration. This may be due to the constant weathering activities that are taking place in the research area. Figure 11 shows the extracted lineaments from band 7 of Landsat 8 data of the research area, they show NE-SW, NW-SE, and EW orientations as confirmed in the rosette diagram (Figure 12). The surface lineaments produced could be the consequences of faults, joints, fractures in the subsurface (28,29,30).

It is a fact that the apparent resistivity measured normal to the strike direction of a structure such as a fracture is greater than apparent resistivity measured along the strike direction, when Schlumberger or Wenner array is used but contrary when crossed square array method is employed (24,31,32). The resistivity anisotropy from RVES varies from NE-SW at shallow and intermediate depths to E-W and NW-SE at a great depth, similar to the results of the rosette diagram. It is further deduced from the table that the directions of anisotropies follow the major directions of faulting in the basement areas (NW - SE, NE - SW, and EW) as shown by [9]. The structures obtained from the geophysical and remote sensing results superimposed on the geological map of the area (Figure 13) updated the existing geology map. It shows a major fracture that originates from augen gneiss in the NE, crosses the granite gneiss in the central, and trends to the SW through the migmatite body.

5. CONCLUSION

This research revealed various structures and lithology that exist within the study area for more understanding of the geology and the mineral alteration types that exist in the area. It is confirmed that the area is underlaid by igneous and metamorphic rocks such as banded gneiss, migmatite, augen gneiss, porphyroblastic granite, granite gneiss, pegmatite vein, and quartz vein with various structures such as faults, folds, fractures, and joints that are aligned in the N-S, NE-SW, NNE-SSW, E-W, ENE-WSW directions. The different orientations suggest that the area has gone through various episodes of deformations, believed to be one of the imprints of Pan-African orogeny. The presence of structures in the area is a prerequisite for groundwater accumulation and hydrothermal mineral deposit emplacement [33]. The demagnetization zones revealed in the RTP map are possible hydrothermal alteration zones.

Band ratios and PCA equally revealed zones of hydrothermal alteration, which suggests mineralization. Various structures deduced from the FVD and Landsat 8 maps of the area of study also align in the same orientation as the structures deduced from geological mapping. This confirms the usefulness of the integration of these methods in structural and lithological mapping. RVES revealed anisotropy as the values of resistivity keep changing with direction, confirming the occurrence of fractures in the area. As a result, these tools and data sources would be recommended for mineral and groundwater explorations, as they would provide timely and cost-effective tools for identifying and narrowing the target areas for groundwater exploration before carrying out further investigations.

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DECLARATIONS

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