Geological and structural analysis using remote sensing for lineament and lithological mapping

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Abstract. The study area forms part of the precambrian to early paleozoic Nigerian Basement Complex. The Nigerian Basement Complex is a polycyclic assemblage of heterogeneous migmatites and gneisses, metasediments and granites that have undergone a complex evolutionary history spanning through Archaean to Pan-African (Late Proterozoic) times. Multispectral images from Landsat 7 ETM+ were utilized to complement field mapping, elucidate lineaments and clearly outline alteration zones. The dominant rock types in the area are gneiss, granites and metasediments with minor lithologies such as aplite dykes, quartzofeldspathic and quartz veins, pegmatites and xenolith. Petrographic studies have shown that the granite comprises of porphyritic and medium to coarse grained varieties that are composed mainly of quartz, feldspar, biotite ± muscovite. The metasediments include pelitic schist and composed of quartz, biotite, feldspar, ± muscovite, ± chlorite and quartzites. These rocks have been deformed, sheared and foliated. The dominant NW-SE to N-S structural trend, follows the general trend of structures resulting from both Pre-Pan-African and Pan-African Orogenies. The geological and structural maps of the study area on a scale of 1:50,000 have been updated.

1. Introduction

The surface area of Nigeria (923,768 km\(^2\)) is covered by crystalline and sedimentary rocks in nearly equal proportions. The Nigerian Basement Complex forms a part of the Pan-African mobile belt and lies between the West African and Congo Cratons (Figure 1) and south of the Tuareg Shield [1, 2]. It is composed of rocks that are highly deformed as a result of various tectonic events with differing intensities. The resultant structures include foliation (alternation of silicic-mafic minerals), minor folds, joints, fractures and faults. Each of the thermotectonic events produced characteristic imprints on the basement rocks. The lithology of the Nigerian Basement Complex is characterized by synclinorial belts of low grade metasediments downfolded into high grade gneisses and migmatites, the whole intruded by batholithic granites. It is characterized by process of several phases of deformation, recrystallization and intrusion, the last of which is the Pan-African orogeny [3, 4]. The basement comprises of three major lithological units [5]:

a) The migmatite gneiss complex which is widespread throughout the country.
b) Metasedimentary and metavolcanic rocks which form schist belts and appear to be dominantly restricted to the western half of the country.
c) The older granites which intrude both the migmatite gneiss complex and the schist belts and have consistently yielded Pan-African ages.

Figure 1. Location of Nigerian sector of the Pan-African Province of West Africa [6]

Majority of the previous works in this area centered mainly on groundwater investigation and the geology of the Basement Complex. Among the previous workers on the basement geology are [3] who mapped Zaria Sheet 102 SW on a scale of 1:50,000, and [4] who mapped degree sheet 21 on a scale of 1:100,000 using photogeological interpretation with selected field traverses.

A need for large scale mapping and to increase our understanding of its structural evolution of parts of Zaria area cannot be overemphasized. Also, most of the structures that have been studied are two prominent joint sets found in the area. One is approximately N-S, frequently in filled with aplite, pegmatite or quartz veins in the granites. The other trends 120°–130° and frequently shows small sinistral displacements [4, 7]. Application of Landsat (ETM+) in geologic mapping was carried out by [8]. However, this work combines both the Landsat (ETM+) application and field studies. Therefore, based on the previous work carried out in the area, more work needs to be done on the analysis of the geological structures of the area and their utilization to determine and reconstruct their geology and evolution.

2. Materials and Method

The study area lies between latitude 11° 00' and 11° 15' N and longitude 7° 30' and 7° 45' E and covers an area of about 770 km² within 1: 50,000 Zaria Sheet 102 SW, Kaduna State, Nigeria. Satellite imageries of the study area were acquired and studied from Landsat 7 Enhanced Thematic Mapper Plus (ETM+). Likewise, an Advanced Spaceborne Thermal Emission and Reflection (ASTER), Global Digital Elevation Model (GDEM) were acquired and draped on the topographic map of the study area and used for the interpretation of physiographic features to aid reconnaissance and detailed field work [9]. Subsequently, subsets of the ETM+ scene were processed using the ENVI 4.5 image processing and analysis software.

ArcGIS 9.1 and GCI Geomatica 9.1 software packages were used in digital processing, spectral enhancement, spectral classification and geospatial analysis of the enhanced images produced for identifying alteration types and lineaments, as well as for lithological classification. Decorrelation stretch was applied in Band 741(false colour composite) to enhance variations in lithologies. The
ENVI 4.5, PCI-Geomatica software was used for digital image processing following the methodology shown in Figure 2.

![Image](https://example.com/image.png)

**Figure 2.** Methodology diagram for processing and enhancement of LandSat Thematic Image [10]

Topographical Maps of the study area were scanned and uploaded into Surfer software 12.0 and was digitized along with a cross section of a selected part of the map (Section A-B) covering all the lithologic units. Zaria Sheet 102 SW was digitized at a scale of 1:50,000. Detailed field mapping using Compass; Global Positioning System (GPS) traversing method was carried out. Other field equipments used include Field Goggles, Geologic Hammer, Silva Ranger 15TD-CL clinometers, Hand lens, and Digital camera (12 Mega pixel). The Compass clinometer was used to measure trend and angle of dip of lithological and structural features on outcrops. The geologic hammer was used to obtain rock samples from outcrops and often used as a scale when snapping geological features. Figure 3 shows photograph of the field equipment used in carrying out field work. The entire area of Sheet 102 SW Zaria was mapped at a scale of 1:50,000.

![Image](https://example.com/image.png)

**Figure 3.** Field equipment

3. Results and discussion
Due to the rock discrimination power of the colour composite images like those used by previous researchers is adopted [11, 12]. For example, 7:5:4, 7:4:1, represented in R: G: B has been applied in this study.

3.1. Digital Elevation Model
Digital cartographic dataset of elevations in xyz coordinates of the study area was draped on topographic map to have a 3-D perspective view of physiographic features. Atlas shader displayed topographic variations with color is presented in Figure 4.
3.2. Lineaments Extraction

The lineaments analysis was undertaken in order to determine the relationship between the lineament trends as the main structural element that has affected the rock units in the study area. Lineaments extraction from Landsat panchromatic image was run with three major steps [11]:

a) Edge detection.

b) Threshold.

c) Lineaments extraction.

Figure 4 shows the main lineament trends extracted in the study area.

![Figure 4. Extracted lineament trends with elevations of structures in the study area](image)

The highest outcrop (Kufena Hill) about 800m above sea level, lies around the center towards the southeastern part of the study area. The lineament frequency plotted on a rose diagram reveals that the most prominent strike direction is NW-SE, while the minor sets occur in the NNW-SSE, NE-SW. Nearly E-W trend and others are subordinate direction. There is good relationship between the lineaments and drainage pattern system distribution. Lineaments in other parts of the area display typical pattern of the joint system in the area. These features in rose plots of data were confirmed from ground truthing.
3.3. Band Rationing

In the current contribution, the band ratios (5/7) and (3/1) were applied on the ETM+ subset covering the study area. The band ratio 5/7 image (Figure 5) clearly discriminates the granite and gneisses (bright tone) and the metasediments (dark tone) [12]. Reversal of band ratio 5/7 was observed for granitoid rocks on the ETM+ band ratio 3/1 as they mainly displayed dark grey tone. Alluvium on terrace around stream channels displayed bright white tone (Figure 5).

![Figure 5](image_url)

**Figure 5.** ETM+ band ratio 5/7 of the study area showing granite and gneisses with high tone white to mist grey

In a simplified form, granite is a light-coloured igneous rock with grains large enough to be visible with the unaided eye. Three minerals make up granite as shown in Figure 6a, Black (Biotite), Grey (Feldspar), and Colourless (Quartz). While a gneiss is a type of metamorphic rock and appears to be layered as presented in Figure 6b. The rocks were originally either igneous or sedimentary rocks but changed that’s why they are layered or have other features as a result of the change. Therefore, the band rationing of these colours clearly identifies some certain types of rocks present in that area from remote sensing imagery.
3.4. Colour Composite

3.4.1. Band 7:4:1
A false colour composite for the study area was produced in order to map lithological variations in the study area. Band 741 (Figure 7) was used to map lithological variations in the study area. Decorrelation stretch was applied to enhance variations in lithologies [13]. This combination is also applicable for agricultural and wetland studies. Urban areas appear in varying shades of magenta while grasslands appear as light green. In floristics, edaphic parameters are associated with topography ranging from communities in well drained soils on upper topographic positions to hydromorphic positions [14]. Thus, this characteristic feature gives granitic environments the ability to bear vegetation.

Figure 6. Granite and Gneiss rocks

Figure 7. Colour composite which includes the band ratio 7:4:1 displayed as RGB showing grassland areas and settlements areas
Legend:
OGP = Porphyritic granite
GG  = Granite gneiss
SP  = Pelitic schist
QTZ = Quartzite

3.4.2. Band 7:5:4
The combination of Band 7:5:4 (Figure 8) provides the best atmospheric penetration. Colour composite images go further to the individual lithological unit discrimination, Image 7:5:4 was able to differentiate individual intrusions (granite) and metasediments which appear light green. Vegetation appears blue and water bodies appear black.

**Figure 8.** Colour composite which include the band ratio 7:5:4 displayed as RGB showing lithological distinction and river channels
The lineament frequency orientation using TNT mips v.6.8 software was plotted on a rose diagram as shown in Figure 9 reveals that the most prominent strike direction is NW-SE, while the minor sets occur in the NE-SW.

Figure 9. Rose (azimuth-frequency) diagram of lineaments orientation [15]

4. Conclusion
Remote sensing studies aided in 2-D perspective view of the study area. Also, Band ratio, principal component analysis method, colour composite method and techniques from Landsat ETM+ aided qualitative discrimination of concealed lithologic boundaries, alteration mapping and extraction of lineaments. The dominant lineament direction as deduced conforms to structure from field observations. Field and petrographic studies have shown that the major lithologic units in the area are granitic gneiss, metasediments (pelitic schist and quartzites) and granites (porphyritic and medium to coarse grained), while quartz veins, aplite dykes and quartzo-feldspathic veins constitute minor rock types. The dominant structural trend NW-SE to NE-SW, follows the general trend of structures resulting from both Pre-Pan-African and Pan-African Orogenies.

The N-S trend with some of the intrusions and foliations implies that they are also Pan-African orogenic structures. Thus, veins and the intrusions-oriented NW-SE are likely Pan-African structures. The joints in the study area are essentially Pan-African structures except for the E-W joints that are oblique to the Pan-African trend. Furthermore, these joints type may be associated with earlier deformational phases. The Pan-African orogeny as a multiphase event imply that these structures are interconnected in time and space. The lineament frequency on a rose diagram reveals that the most prominent strike direction is NW-SE, while the minor sets occur in the NE-SW. Knowledge of this strike direction, can help the disaster management authorities to proffer necessary safety measures when disaster occurs. Therefore, the geological and structural maps of the study area on a scale of 1:50,000 have been updated.

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