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Structural Interpretation of the Jos-Bukuru Younger Granite Ring Complexes Inferred from Landsat-TM Data

OPARA A.I.[1], UDOETE R. L.[1], EMBERGA T.T.[2,*], ECHETAMA H.N.[1], UGWUEGBU I.E.[1], NWOKOCHA K.C.[1], IJEOMA K.C.[1], CHINAKA J.C.[3], ONYEMA J.C[3]

[1]Department of Geosciences, Federal University of Technology, PMB 1526, Owerri Imo state, Nigeria
[2]Department of Physics/Industrial Physics, Federal Polytechnic Nekede, Owerri
[3]Department of Physics, Imo State University, Owerri
*Corresponding author: terhemba4sure@yahoo.com

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Abstract A detailed study of the Landsat Thematic Mapper(Landsat-TM) image over Jos Plateau, Nigeria was carried out to identify linear geologic features that could be attributed to paleo-tectonic and/or neo-tectonic structures and to infer the influence of such structures on mineralization in the study area. The data was geo-referenced using the coordinates of the topographic map sheet of Naraguta. The application of directional edge enhancement techniques to band 5 of the Landsat-TM data using convolution models in ILWIS 3.2 academic software were to further enhance these linear features. Results of the structural analyses revealed several lineaments at the northwestern, central and southwestern parts of the study area. Trend analysis of the lineaments revealed structural trends in the NW-SE, NE-SW, N-S and E-W directions with the NW-SE and NE-SW been the dominant trends in the area. These trends correspond to the positions and directions of the paleo-tectonic fracture zones in the area. High lineament densities were also observed in areas where basement rocks outcrop or are close to the surface. The relationship between lineament densities and Younger granites occurrences in the study area is an indication of tectonic control probably associated with paleo-tectonic structures. This correlation is an indication that the emplacement of the Younger granite ring complexes may be associated with epeirogenic uplift. The epeirogenic uplift is believed to result from the intrusion of large masses of basic magmatic materials into the lower part of the continental crust in the area. The marked relationship between the Younger granites and the lineaments is believed to have controlled mineralization in the study area.

Keywords: *Landsat-TM, lineaments, uplift, mineralization, younger granites, tectonic trend, Nigeria*

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1. Introduction

Jos Plateau is in the North-central region of Nigeria and is located between longitudes $7^0 30 – 10^0 00^1$E and latitude $8^0 00 – 11^0 30^1$N, covering an area of about 22000km^2. The physiography of the study area can be described based on the nature, geomorphology and the structural elements in the Jos - Bukuru Ring Complexes. Jos - Bukuru complex lies at the focal point of younger granite magmatic activity in Nigeria. Several individual complexes have been identified with varying sizes and named after their localities with individual massifs ranging from 640km^2 to less than 1.68km^2 [23]. The Younger Granites are believed to be discordant high level intrusions emplaced by means of piecemeal stopping through the collapsed central block [23]. Their outlines are either circular or elliptical. Several cycles of intrusions occur within one complex. The sizes of many of the structures are due to overlapping and superposition of separate intrusive cycles [2,9,33,34]. The topography of the Jos-Plateau comprises of chains of highlands of variable heights associated with areas of almost flat topography. The drainage pattern of the study area is mainly dendritic while the vegetation is characterized by tall grasses, shrubs and stunted trees. The geology of Jos- Plateau comprises of plutonic and volcanic rocks belonging to four main age groups. The rocks of Jurassic age (Younger Granites, 140-190MA), Precambrian rocks (>500MA, crystalline basement rocks, migmatites, gneisses) and intrusive older granites of Pan – African Orogeny are the predominant rocks of the study area. The Pan African Orogeny occurred over the African continent and subsequently led to structural deformation and regional metamorphism.

The application of satellite data for geological mapping is one of the most common remote sensing applications in the world today, used for identification of rock types at the surface in areas of little or no vegetation. The structural information revealed by the lineaments is a very important piece of information available to the geologist from satellite images. Many of the visual interpretation techniques of photo-geology can be applied to satellite remote sensing data, but extended spectrally to include new paths of the electromagnetic spectrum. The use of digital imagery as provided by the satellite data creates some specific advantages when it comes to image enhancement. This is true for enhancement of spectral features exemplified by principal component analysis in the form of decorrelation stretch (decorrelation stretching is an excellent means of accentuating colour variation within an image as an aid to visual interpretation), and spatial enhancement by high-pass filtering for detection of subtle geological features.

Similarly, the use of satellite imagery for regional mapping of geologic units and structures has long been demonstrated as a vital tool for regional geologic mapping. This is as result of its ease of operation, speed, accuracy, low cost and coverage. In addition, advancements lately in satellite and digital technologies have led to remarkable improvements in this technique [29,30]. Several studies have emphasized the importance of lineament interpretations and digital analysis in mapping major mineral deposits and have therefore revealed a strong correlation between mineral deposits and lineaments [5,25]. Linear features shown on remote sensing imagery are of regional extent and their study often provide insights not only to the location of the mineral deposits, but also to metallogenic theories as well [25]. Furthermore, many studies have shown that remotely sensed data can be employed for improved geologic mapping [11,15]. Most mineral deposits are therefore related to some type of deformation of the lithosphere, and most theories of ore formation and concentration embodies tectonic or deformational concepts [4,25]. Some lineament patterns have been defined to be the most favourable structural conditions in control of various mineral deposits. They include the traces of major regional lineaments, the intersection of major lineaments or both major (regional) and local lineaments, lineaments of tensional nature, local highest concentration (or density) of lineaments, between echelon lineaments, and lineaments associated with circular features like the Younger granite ring dykes. They are generally manifested by topography (including straight stream segments), vegetation, or soil type and are observable on landsat imagery. Finally, the drainage system which develops on a regional scale is controlled by the slope of the surface and the type and attitudes of the underlying rocks. Drainage is studied in this work according to its pattern, texture or density. It is probably the most important single identifier of landforms. Linear features are clearly discernible on landsat images and often indicate the form and position of individual folds, faults, joints, veins, lithologic contacts, and other geologic features that may lead to the location of individual mineral deposits. They often indicate the general geometry of subsurface structures of an area thereby providing a regional structural pattern.

The interpretation of landsat imagery using manual or digital image processing has found application in developing new maps and or revising and improving the pioneer maps on poorly outcropping areas [11,15]. They have also found great application in structural and tectonic mapping [37]. Regional structural analysis by this process is effective and more with radar interpretation [10,24]. Broad lithological information can be determined from a number of parameters (such as general geologic setting, weathering, landforms, drainage, structural features, soil, vegetation and spectral characteristics) observed from remote sensing data. The use of Landsat imagery for geologic studies received a boost in Nigeria over a decade ago with the creation of the National Space Research and Development Agency (NARSDA), a governmental agency responsible for the launching and monitoring of earth observation and telecommunication satellites [6,16,26]. Bala et al [7] used Landsat TM imagery to identify lineaments that may be favourable for the occurrence of groundwater, especially in the crystalline terrains of Dutsin-Ma, Northwestern Nigeria. Ologun [26] generated and developed filtered images and clusters in order to obtain structural and geologic maps of the Jos plateau while Igbokwe and Ayomaya [16] carried out gully erosion mapping and monitoring in parts of southeastern Nigeria using satellite imagery.

This research work therefore presents a landsat based structural interpretation of the study area with the objectives of mapping the land forms, delineating the linear features and their structural trends with the aim of making inferences to their effect on mineralization in the study area. The underlying reason for fracture and lineament analyses of the study area is that zones of fracture concentrations can be obtained, and through proper interpretation, information on the structural deformations occurring in a region can be revealed. This is because the study area has been affected by so many tectonic events which affected the geology of the area and left several imprints. This work therefore is an attempt to carry out a detailed geological interpretation of the area using Landsat Thematic Mapper. Thematic Mapper (TM) images allow photographic enlargement up to 1: 100,000 and 1:50,000 thereby enabling a more detailed analysis which may also take into consideration, features included in the lineation class. In basement areas, fracture zones and fracture crossing points are generally the main site where groundwater may be exploited within the study area. The data used were obtained as Landsat imagery from Thematic Mapper (TM) 17th November, 1986 and was later processed by using ILWIS 3.2 academic.

1.1. Climate, Physiography and Gology of the Study Area

The Jos plateau lies within the Northern Guinea savanna vegetation zone which is an open wood land with tall grasses, shrubs and stunted trees. However, the native vegetation has been considerably altered by human activities. Throughout the area, there is a close relationship between rock type and scenery [1]. The climate of Jos-plateau is characterized by a mean annual rainfall of 1260mm (1,050 – 1403mm), peaking between july and august. The mean annual temperature is about 22°C, but mean monthly values vary between 19.4^{0}c in the coolest month of december when the area comes under the influence of the cool and dry (desiccating) north – easterly tropical continental air mass (harmattan) and 24.5^{0}c in the hottest month of april. The physiography of the study area can be described based on the nature and the structural elements in the Jos-Bukuru ring complexes. During the initial survey of the Jos Plateau Tin fields, Falconer and Raeburn [14] recognized the prominent position of the Jos-Bukuru granite as a source of cassiterite. He noted the heterogeneity of the complex, but attributed the textural variations in the granite to proximity to the roof of the batholiths. The rhyolites and granite-porphyries at the northern end of the complex were studied by earlier scholars who recognized the Neil's Valley Structure to be a ring-complex [22].

The Jos- Bukuru Ring complex is elliptical in surface plan with the longer axis extending to a distance of 30 miles (48km) from the Shere Hills in the north-east to the Forum River in the south. The elevation above sea level ranges from 3,800ft (1158 meter) near the west and north margins to nearly 6,000ft (1828meter) around Shere Hills.

Figure 1 below is the geology map of Nigeria showing the Younger Granite Ring Complexes of Nigeria. The greater part of the area lies between 4,100ft (1250meter) and 4500ft (1372meter) and presents the typical plateau landscape of treeless, grassy plains with scattered groups of low rocky hills. Nearly fifty Younger Granite Massifs are known, varying greatly in size, many of the larger ones being made up of two or more overlapping ring complexes [23]. They occur in a broad N–S zone, 400 x 150km, centered on the Jos Plateau where the greatest concentrations of ring complexes are found [13,18,36]. The emplacement of the Younger Granites is completely unrelated to orogenic activity. Their age is Jurassic, around 160 to 170 million years; the older granites and accompanying metamorphism of the basement are dated at about 500 to 600 million years, and represent the pan African orogeny in Nigeria [17,18,23,36].

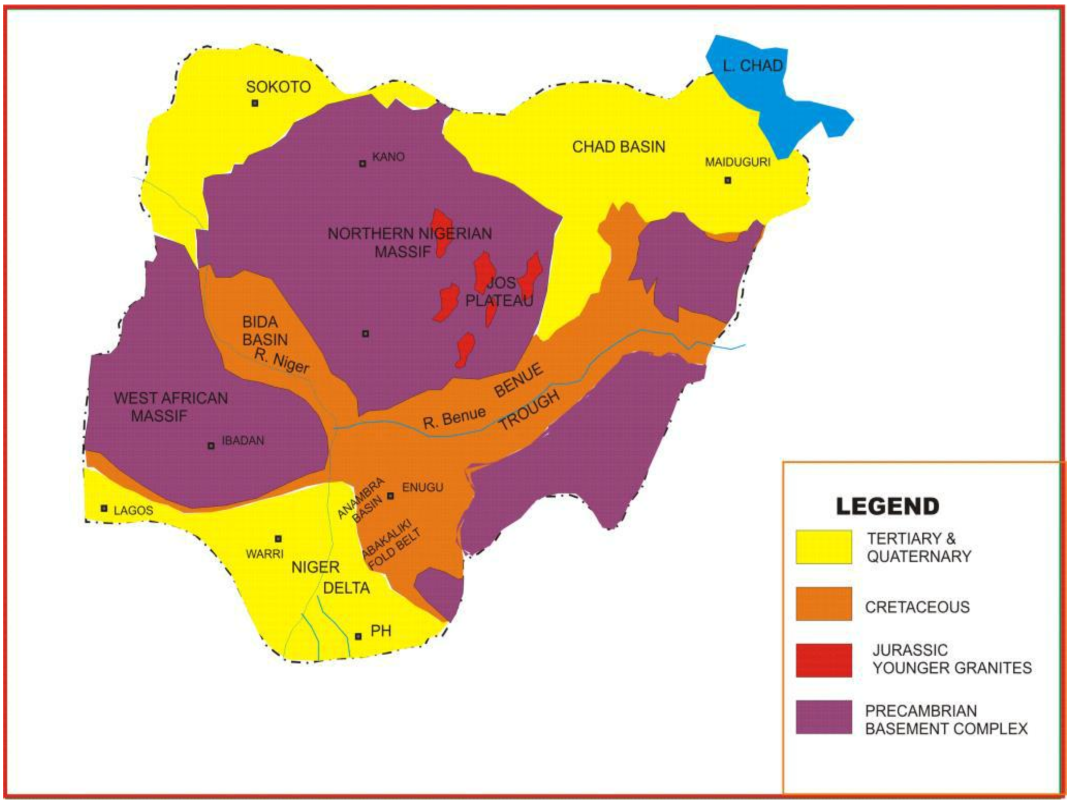

Figure 1. Geology map of Nigeria showing the younger granite ring complexes

The Nigerian Younger Granite Ring complexes are a series of petrologically distinctive crystalline igneous rocks of granitic composition [23]. Several individual complexes have been identified with varying sizes and named after their localities with individual massifs ranging from 640km^2 to less than 1.68km^2 [23]. The Younger Granites are believed to be discordant high level intrusions emplaced by means of piecemeal stopping through the collapsed central block [23]. Their outlines are either circular or elliptical. Several cycles of intrusions occur within one complex. The sizes of many of the structures are due to overlapping and superposition of separate intrusive cycles [2,9,13,14,33,34]. The Younger Granites were preceded by extensive acid volcanism and emplaced by ring faulting and block subsidence. Granites and rhyolites underlay more than 90 percent of the total area of the Younger Granite province. Intermediate and basic rocks occur in many complexes. Their emplacement is completely unrelated to orogenic activity associated with the study area [2,23,34]. Their age is Jurassic, around 160 to 170 million years; the Older Granites and the accompanying metamorphism of the basement are dated at about 500 to 600 million years, and represent the Pan African Orogeny in Nigeria [2,9]. However, it seem likely that emplacement of the Younger Granites was associated with epeirogenic uplift [34]. Indirect evidence for this is lack of sediments associated with the volcanic rocks of the younger granite age, which are apparently erupted on to a land surface undergoing erosion, not deposition [34].

The Nigerian Younger Granites are part only of a much larger igneous province extending far to the north in Niger Republic [8]. Here there are two main areas of ring complex occurrence, both on structural culminations where uplifted basement rocks emerge from the surrounding younger sedimentary formations. The form of the Jos-Bukuru complex has been determined by a major elliptical ring-fracture which extends around the northern, western and southern margins of the massif and embraces the separate Jarawa complex to the east. The Jos-Bukuru and Jarawa group of intrusions present the best examples in the province of large scale cauldron subsidence and the superposition of ring structures [23]. The complex exhibits an extremely intricate pattern of separate granite intrusion. It is certain that large-scale ring-faulting and cauldron subsidence have operated during the initial stages of granite emplacement but the original pattern may have been extensively modified by piece-meal stopping and the superposition of later cauldron structures [23]. The sequence of magmatic activity can be divided into an early volcanic cycle and four separate latter cycles of granite intrusion.

2. Materials and Methods

Eros EDC prepared and supplied the dataset in the new National Landsat Archive Production System (NLAPS), the National Data Format (NDF) to the Earth Science Data Interface (ESDI) from where the image was downloaded at the National Center for Remote Sensing, Jos. The image organization is in Band Sequential (BSQ) and the same data, in raster format, was presented in seven bands. The image is part of path 188 row 53 scene of 17th November, 1986. Ground Control Points (GCPs) and satellite orbit information were used to rectify the imagery. Thus, image rectification was to existing geo-coded Landsat MSS and SPOT Multispectral data (that is, image to image geo-coding), utilizing the Universal Transverse Mercator (UTM) Coordinate System, Clarke 1880 Spheroid. Each scene was also radiometrically corrected. The data was further processed using Integrated Land and Water Information System (ILWIS 3.1) academic, IDRISSI, and ArcGIS 10.2 Softwares. Integrated Land and Water Information System (ILWIS) software was used for creating several themes or layers from the satellite image. This software has the capabilities for various image enhancement routines such as linear enhancement, statistical analysis, principal component analysis, etc.

The following image analysis techniques were carried out on the acquired Landsat image: contrast stretching was carried out on the acquired landsat data. A histogram equalization stretch was carried out using the appropriate module in ILWIS 3.1 academic. This was done for all the seven TM bands used. The result was compared to that of a linear stretch with saturation and it was found that for this study, a histogram equalization stretch is most suitable. Similarly, digital filtering was carried out on the data. Two major filters were applied to the band 5 imagery using ILWIS 3.1 academic filter module; these include the laplace and edge enhancement filters. This was done to increase the spatial frequency of the imagery so as to enhance high frequency features, which may include fractures. Lineaments were digitized on screen using the mouse. The resulting lineament vector layers were then rasterized by using the segment density module in ILWIS 3.1 academic. The resulting raster image has a pixel size of 0.25 x 0.25km. Finally, composite image generation was carried out in the study area. Various colour composite imageries were generated using the IDRISI composite module. This resulted into 24-bit images with original values and stretched saturation points presented in Red-Green- Blue (RGB) colour tones. The appearance of different surface features for the different colour composite band ratio images is summarized in Table 1 below.

Table 1. Appearance of Features on Composite Images.

	TRUE COLOUR	FALSE COLOUR	SWIR (GEOCOVER)
	Red: Band 3	Red: Band 4	Red: Band 7
	Green: Band 2	Green: Band 3	Green: Band 4
	Blue: Band 1	Blue: Band 2	Blue: Band 2
Trees and Bushes	Olive Green	Red	Shades of green
Crops	Medium to light Green	Pink to red	Shades of green
Wet land vegetation	Dark green to black	Dark red	Shades of green
Urban areas	White to light blue	Blue to gray	Lavender
Water	Shades of blue & green	Shades of blue	Black to dark blue
Bare soil	White to light gray	Blue to gray	Magenta, lavender, or pale pink.

Another image processing technique carried out was image classification. Unsupervised classification was carried out using the cluster module in ILWIS 3.1 academic. Five clusters were chosen and were interpreted based on information gained from pre-existing geologic maps of the study area. The cluster image is a product of an RGB 127 colour composite from the image. Finally, image enhancement was carried out to improve the visual quality of the imagery. This was done based on the intended use of the interpreted results. Two main approaches were involved: the imagery was enhanced on the basis of individual and neighbouring pixels (spatial), and on the multi-band basis for which values of individual pixels were transformed (spectral).

3. Presentation of Result

In this study, only linear features equal to or greater than 1km in length were considered. Laplace and edge enhancement filters (Figure 2 and Figure 3) were used to enhance linear features. Similarly, lineament and lineament length density maps are presented in Figure 4 and Figure 5 respectively. Thus the result of the structural analysis revealed that numerous fractures and lineations occur at the northeastern and southwestern parts of the study area. The major orientations of the lineation are in the NE- SW and NW-SE directions. The length of all lineaments were measured, computed and used to generate the rose diagram shown in Figure 6. The trend surface analysis of the structural features of the ring complexes in relation to the lineaments (Figure 6) based on the rose diagram revealed several trends of the lineaments in the NE-SW, NW-SE, N-S and E-W directions with the major and dominant structural trends being in the NE-SW and NW-SE directions.

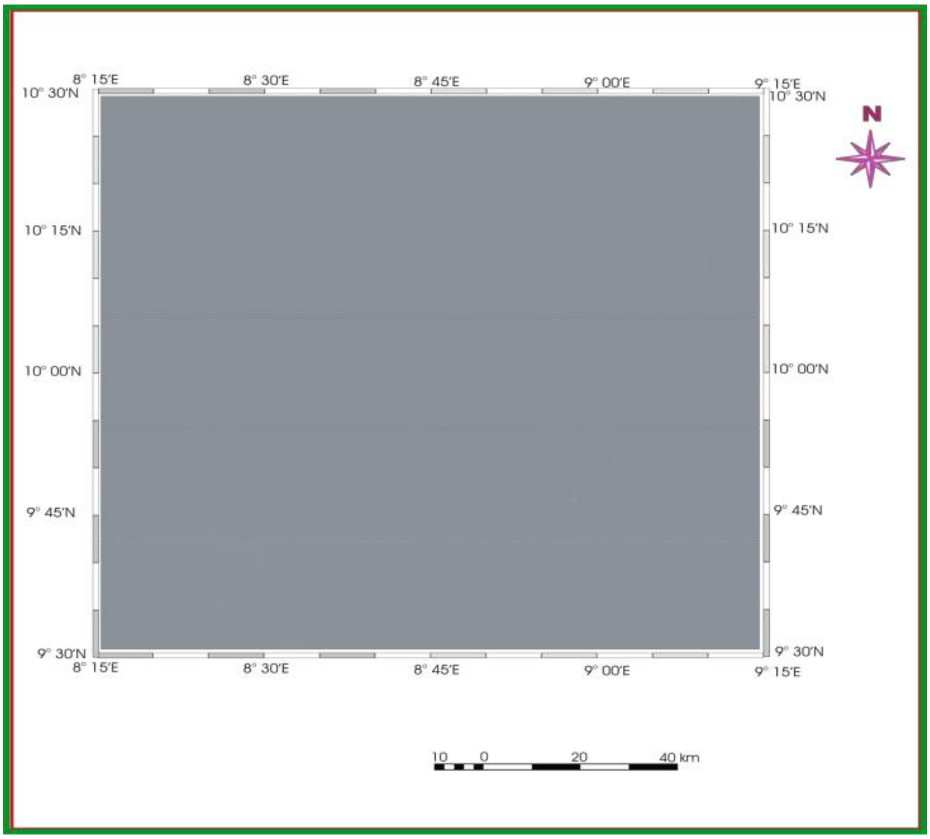

Figure 2. Laplace filter map of the study area

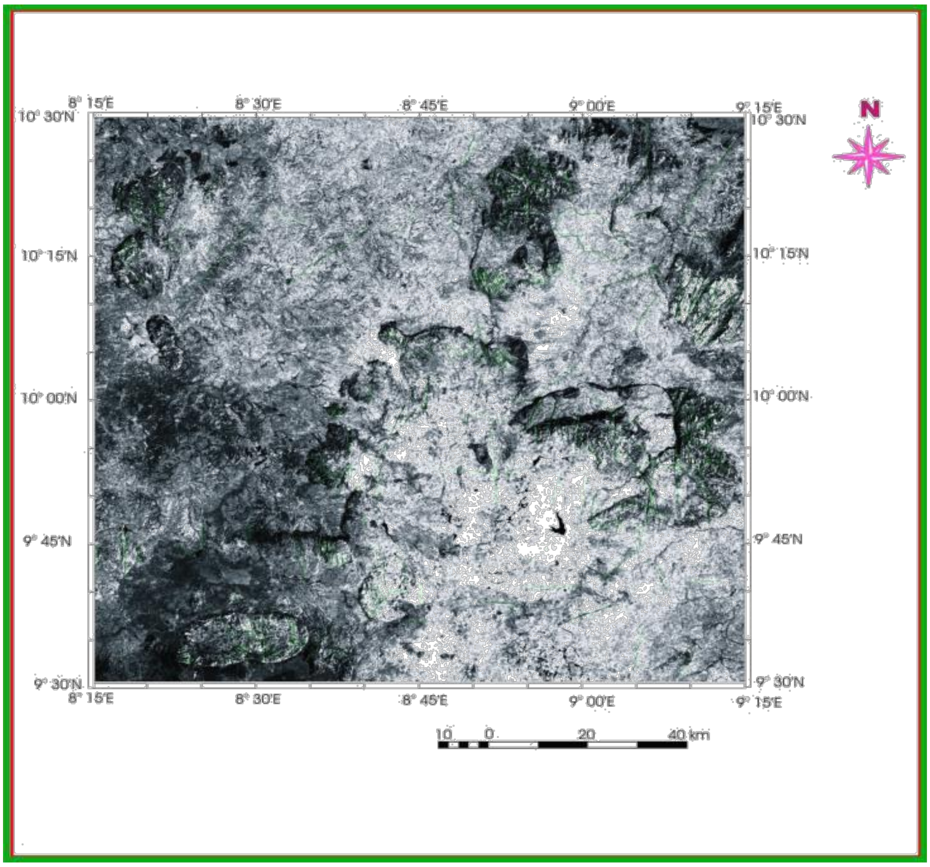

Figure 3. Edge enhancement map of the study area showing the Younger Granite Ring complexes (dark greyish areas)

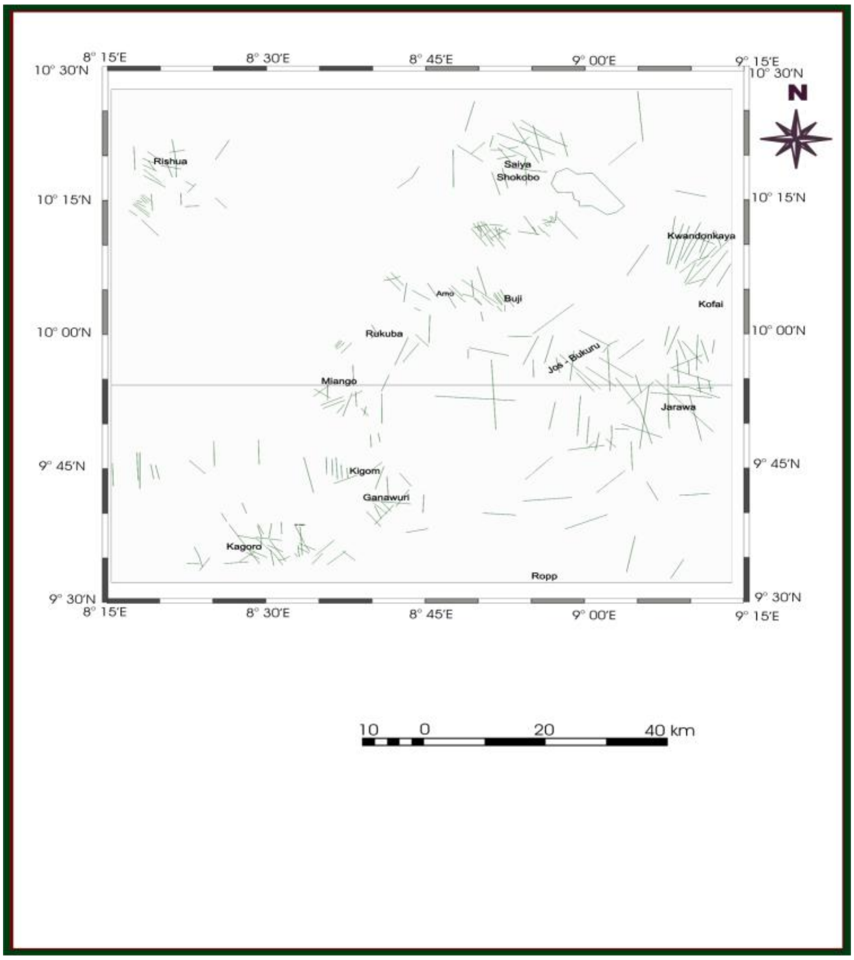

Figure 4. Lineament map of the study area showing numerous lineaments especially within the areas interpreted as Young Granite Ring complexes

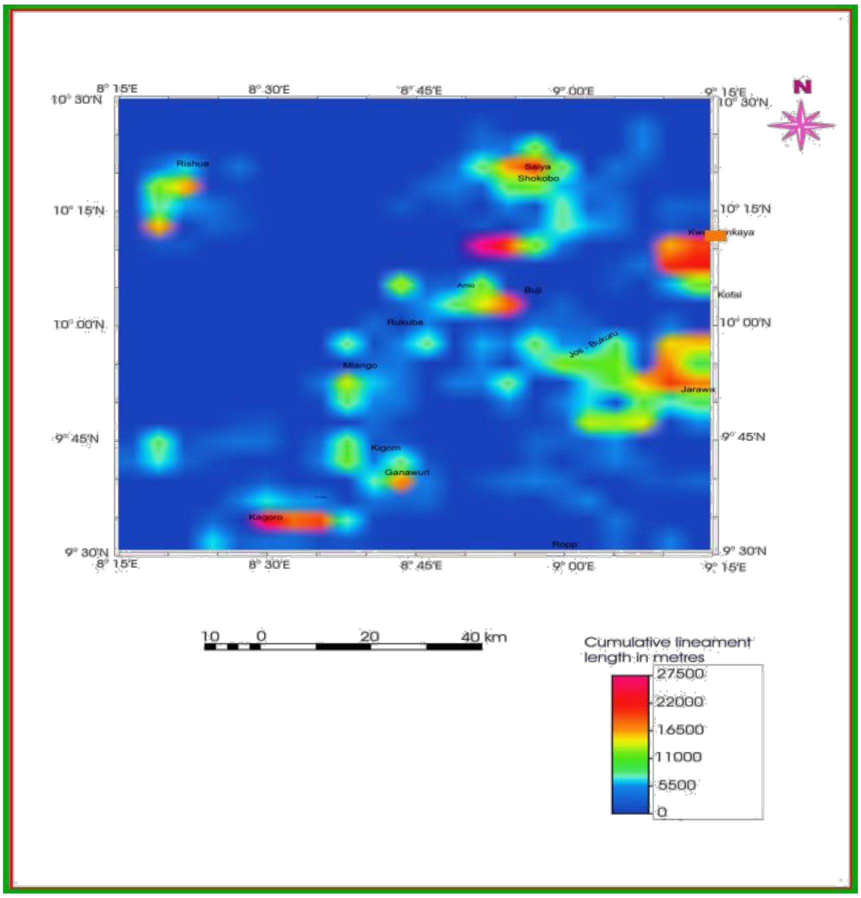

Figure 5. Lineament density map of the study area showing higher densities within the Younger Granite Ring complexes

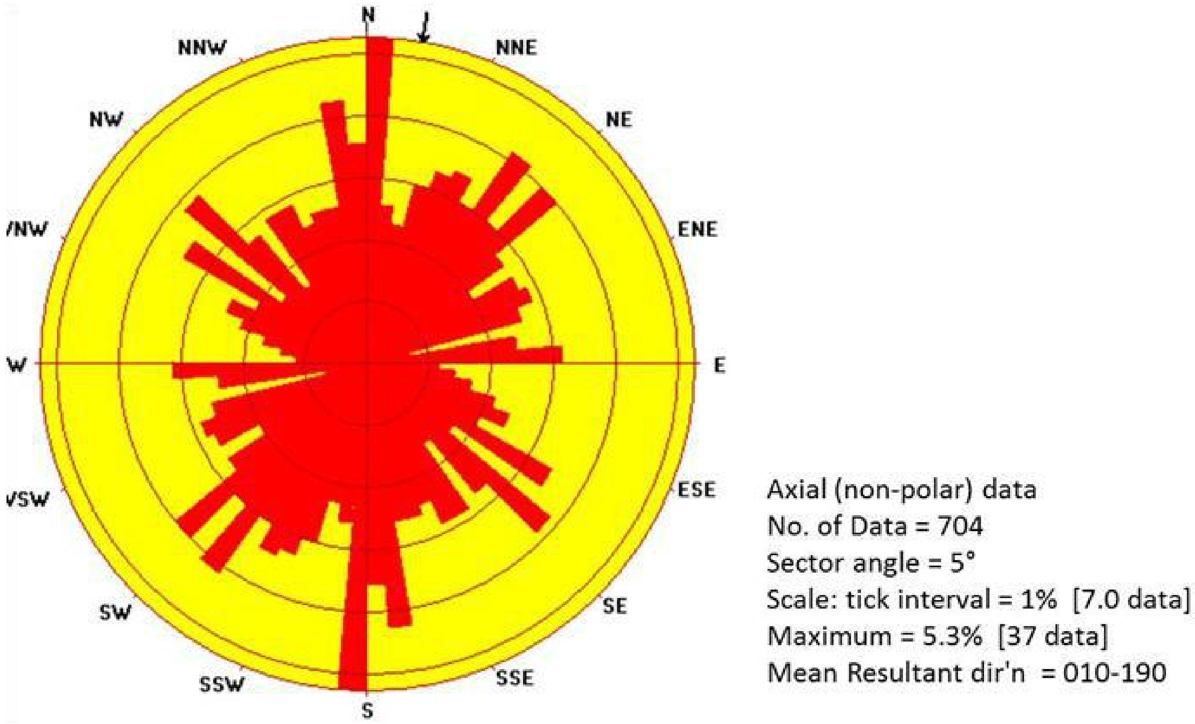

Figure 6. Azimuth frequency diagram(Rose diagram) generated from the lineaments of the study area

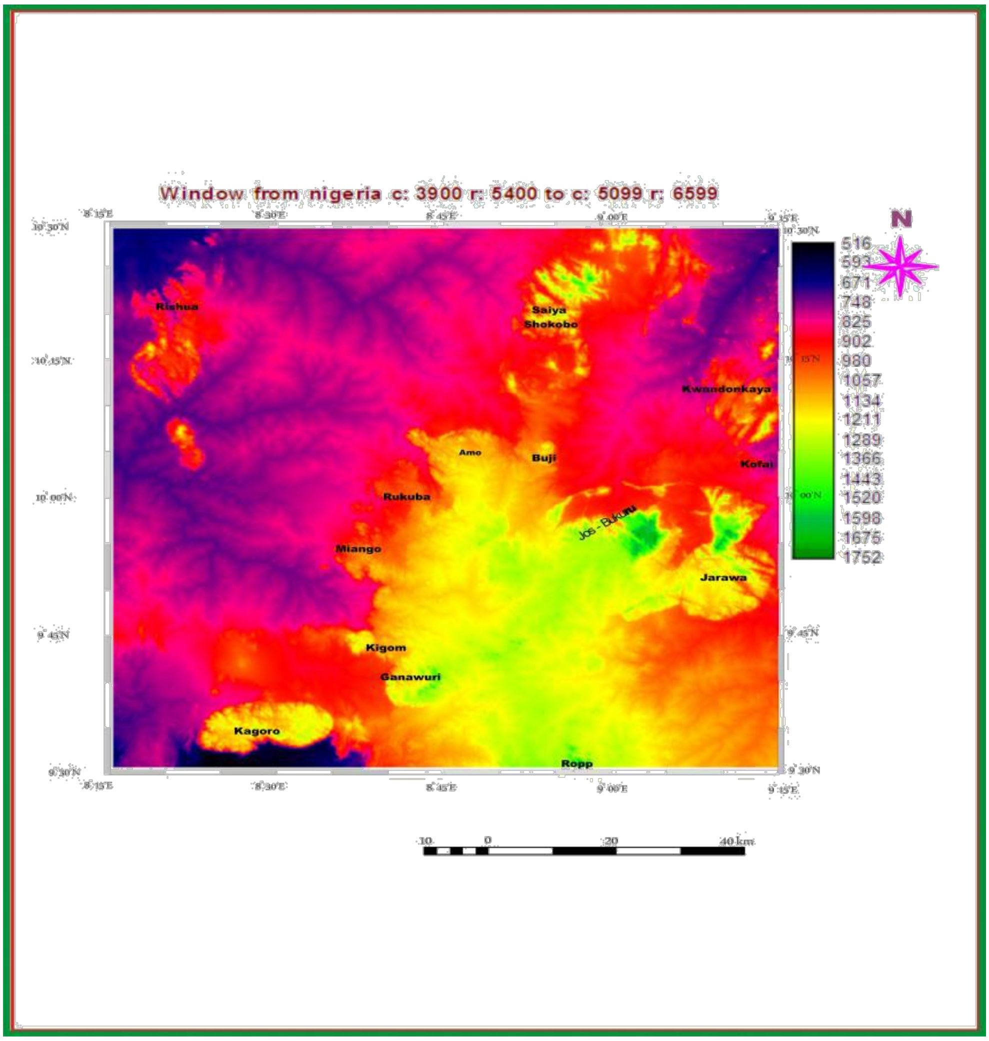

Figure 7. Digital elevation map (DTM) of the study area

The Landsat-TM data of the study area was digitally processed and enhanced to produce single band images, band ratios, colour composites, and classified images complemented by digitized geologic maps of the study area. Drainage patterns and textures, bare rocks and vegetated areas were enhanced in single band images while secondary features such as iron staining (Gossan) and clay rich sediments were identified in image ratios. Similarly, the SRTM data was used together with the landsat-TM data in the production of the digital elevation model (DEM) which proved very reliable in the identification of basement complex (Figure 7). The colour composites were used as background data for both supervised and unsupervised image classification. The Landsat-TM data obtained was further subjected to various image enhancement and transformation routines. For the image transformation, band ratios were generated using the calculator module in IDRISI 32. The ratios generated (3/4, 4/2, 3/1, 5/4) were employed to reduce the effects of shadowing as well as to enhance the detection of certain features of interest. For image enhancement, three bands (RGB) colour composites were created using the composite module of IDRISI 32. This process was employed to enhance the spectral quality of the images. Generated composites include RGB 432, RGB 532, RGB 753 and NDVI composite. Figure 8 and Figure 9 show typical composite maps generated in the study area. The NDVI map (Figure 9) was used to establish a relationship between structure, drainage and vegetation within the Younger Granite Ring Complexes. This study revealed an indirect relationship between structures /lineaments and NDVI composite maps especially in basement areas. Areas of intense structural deformation with high lineament density were observed to be associated with higher NDVI values. Similarly, unsupervised classification was carried out using the cluster module in ILWIS 3.2 academic. Five clusters were chosen for this study (Figure 9) and were interpreted based on information from pre-existing geologic maps of the study area. From the generated colour composites, darker colours corresponded to the Younger Granite Ring complexes. Structurally, there is a correlation of the Younger Granite Ring Structures with areas of intense deformation as revealed by the lineaments (Figure 8). Blue (both dark and light) colours partly correspond to basement complex rocks whereas yellow colours correspond to areas covered by volcanic rocks.

In addition, the correlation of the lineament map (Figure 4) and the younger granite distribution map (Figure 11) revealed that the emplacement of the lavas and the granitic rocks may have been controlled by ring fracturing and large-scale cauldron subsidence [4]. Besides, the granitic bodies are generally fractured and fissured with these weak zones used as pathways for the greisenisation fluids [23]. Thus, within the younger granite province, in addition to the N-S, NE-SW and NW-SE fracture systems, ring fractures were developed and the granitic complexes themselves were fissured and mineralized. The lineament density contour map of the study area was compared with the primary mineral occurrence map of the study area. A good correlation was established between the areas where most primary minerals like iron, tin and cassiterite have been reported and areas of high lineament density. The correlation revealed that primary mineralization in the study area may have been tectonically controlled.

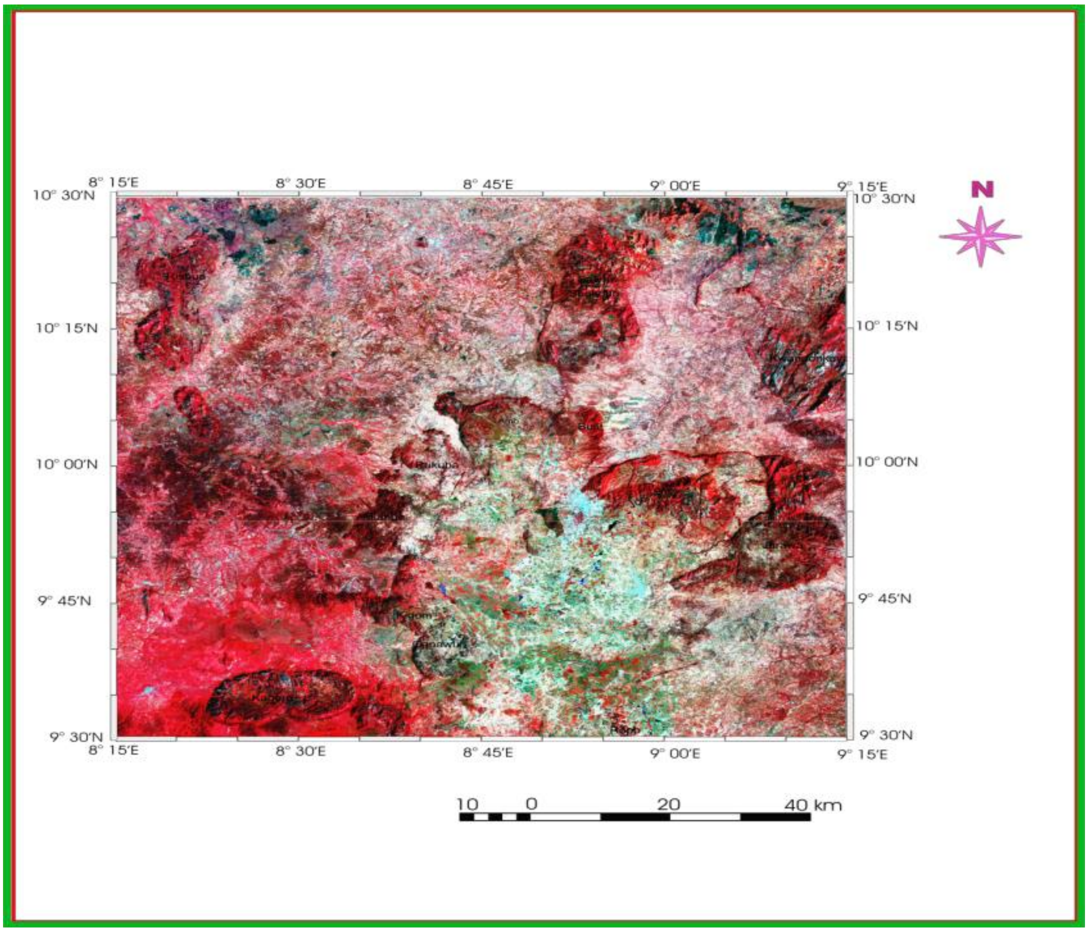

Figure 8. False colour (RGB 432) map of the study area

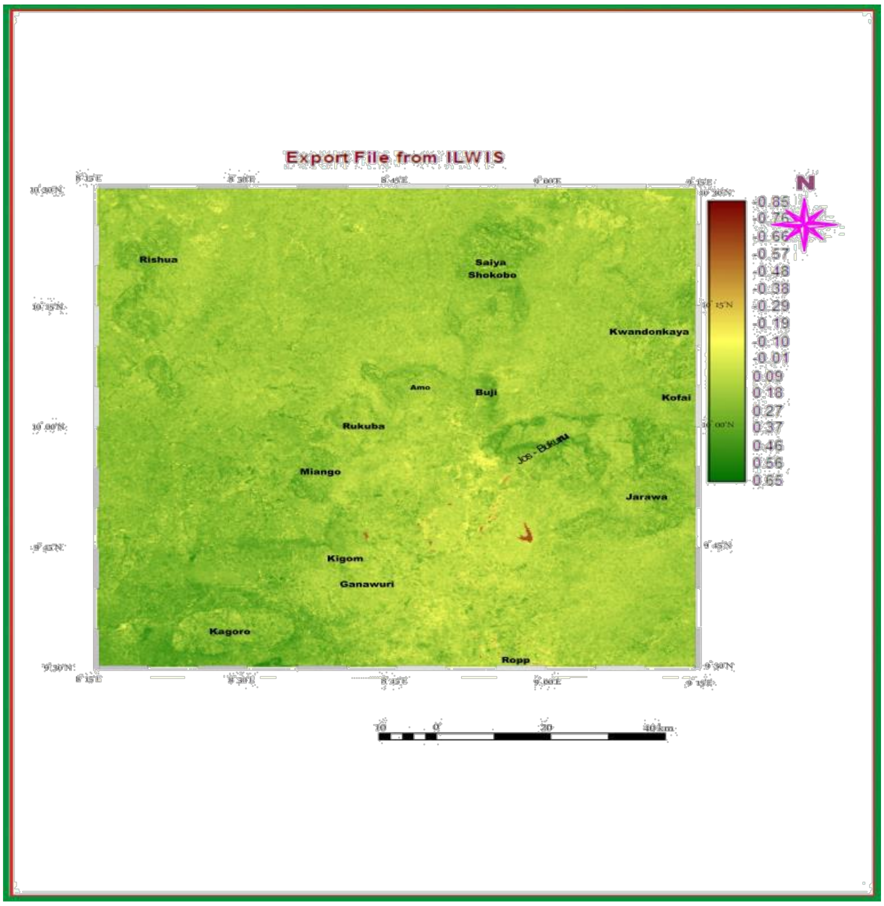

Figure 9. Normalized Density Vegetation Index map of the study area

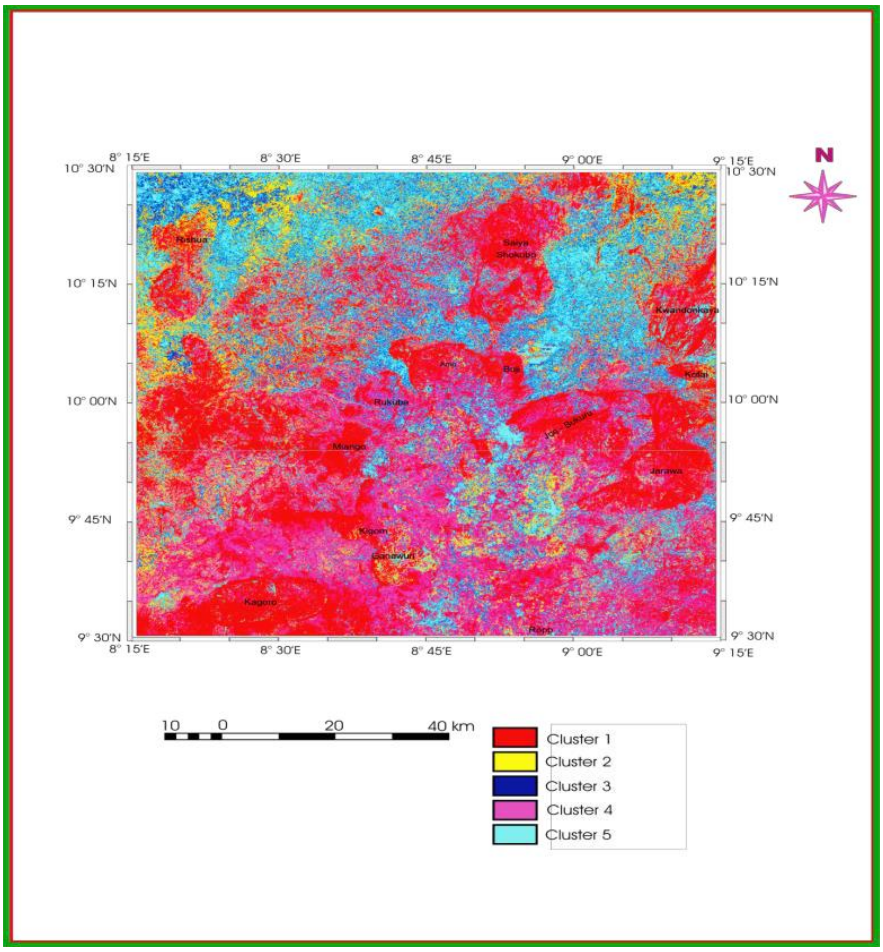

Figure 10. Unsupervised Image classification map of the study area

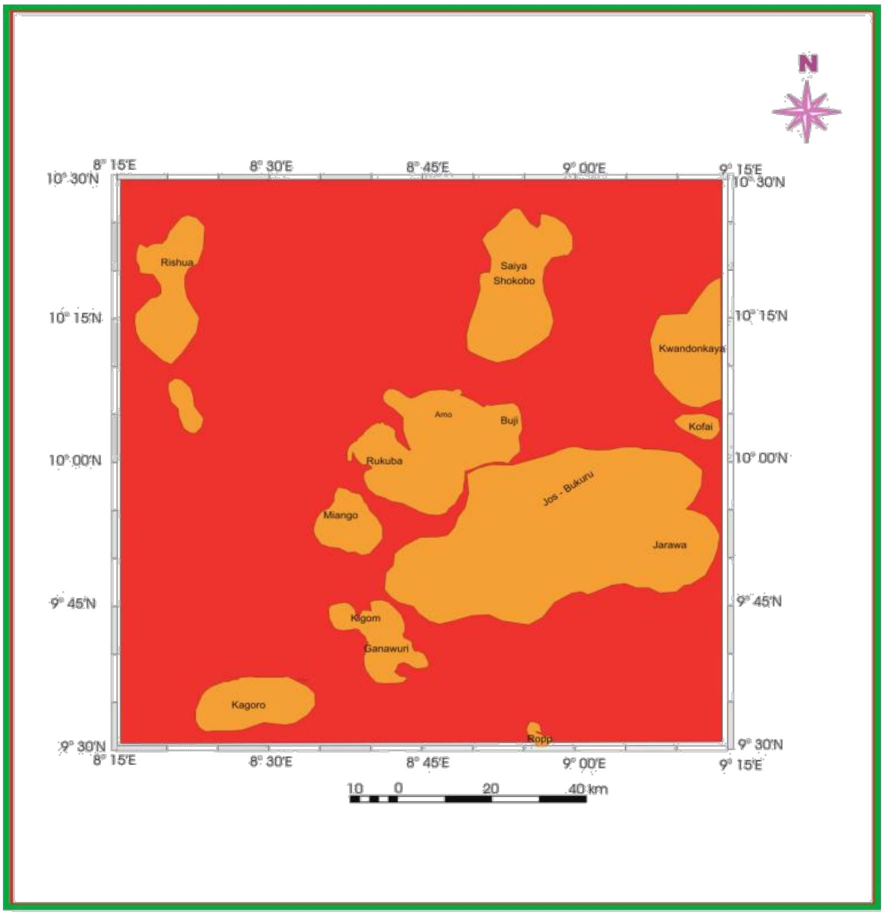

Figure 11. Map showing the distribution of the younger granite ring complexes of the study

4. Discussion

Structural interpretation in the study area revealed four structural trends in the NE-SW, NW-SE, N-S and E-W directions with the dominant trends being in the NE-SW and NW-SE directions. Generally, the fractures in the Nigerian Basement complexes and associated areas are oriented in four principal directions: E-W, N-S, NE-SW and NW-SE [7,12]. The E–W fractures are discernible locally, having been overprinted by latter events. The N-S fractures are very prominent and are often conformable with other geological trends. They have been identified on “imageries” as depressions and prominent scarp surfaces and appear to have determined the causes of the major N-S flowing streams. They are traceable across most part of the country. The N-S fracture are also found on both sides of the River Niger and around the Jos-plateau. These fractures are products of brittle deformation and are marked in the field by considerable shearing and brecciation. There is no doubt that the fractures are of regional extent as similar structures have been identified in the Tuareg area of Niger Republic.

Furthermore, each complex often exhibits a centripetal arrangement of successive phases along a linear direction. The spatial arrangement of the totality of the complexes suggests the basement control of the igneous activities and the reactivation of the existing lines of weakness during the Mesozoic. Thus, within the younger granite province, in addition to the N-S, NE-SW, and NW-SE fracture systems, ring fractures were developed and granitic complexes themselves were fissured and mineralized [2,9,33,34]. The emplacement of the lavas and the granitic rocks were controlled by ring fracturing and large scale cauldron subsidence. Numerous ring dykes and cone sheets which fringe the complexes are evidence of the ring structures. Besides, the granitic bodies were fractured such that fissures and crushed zones developed in them serve as pathways for the greisenisation fluids [2,9,23,33,34]. Results of this study are in line with previous works, which suggested that Nigeria has a complex network of fractures and lineaments with dominant directions of NE-SW, NW-SE and N-S [4,12,28,35].

A comparison of the lineament density map with the primary mineral occurrences map of the study area showed a good correlation indicating that primary mineralization in the area may be tectonically controlled [5]. Primary ore bodies in Nigeria are probably oriented following lineament trends. There is therefore a good correlation between the lineament density map and the areas where the occurrence of most primary minerals like iron, cassiterite, lead-zinc and uranium have been reported. Finally, Melton explained that structural features such as faults, joints and fractures besides controlling primary mineralization may also control drainage. Lineaments most often are underlain by zones of localized weathering and increased permeability and porosity. Therefore, lineament maps such as the lineament density map produced in this work may be a tool that can enhance the detection of areas of high groundwater recharge, flow and development. Groundwater flow and yield in mountainous areas composed of crystalline rocks with several features and faults are governed mainly by flow dynamics within the lineaments. Therefore, the distribution and density of lineaments may be closely related to groundwater well productivity or yield. Detailed study of the lineament trends in the area revealed that the granite province of the Jos plateau constitutes a distinct unit as it is bounded by northerly fractures. Similarly, many of the lineaments are drainage lines. This means that the drainage is structurally controlled [33]. However, the absence of visible fractures and lineaments in parts of the study area may not be indicative of complete absence of geological structures. High lineament frequencies are obtained in areas where basement rocks outcrop or are closer to the surface (i.e. area with thin overburden) whereas low lineament frequencies are characteristics of areas with deeply buried basement rocks.

5. Summary, Conclusion and Recommendation

This study has demonstrated that Landsat-TM has a lot of research potentials for geological application. In this study, only linear features equal to or greater than 1km in length were considered which may be fault or dykes and further classified according to their length and photographic expression. This work revealed that N -S, NE-SW and NW-SE are well developed principal structural trends both on the crystalline basement complex as well as the cretaceous and younger sediments. This indicates that these fractures may have been active since geological times. The structural trends were found to be controlled by structures in the underlying Precambrian rock of the Basement complex. Lithologic control was deduced from the observed variation in both the number and the frequencies of the system of lineaments. Finally, a good correlation was established between the areas where the occurrence of most primary minerals like tin ore, iron, cassiterite, are known to occur with areas of high lineament density. This correlation shows that primary mineralization in the study area may have been tectonically controlled.

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