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Full Length Research Article

MAPPING AND ANALYSIS OF THE DENSITY OF LINEAMENTS OF THE YOUNGER GRANITE COMPLEXES OF JOS AND ENVIRONS NORTHCENTRAL NIGERIA

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ABSTRACT
Mapping and analysis of the density of lineaments around the Younger Granite complexes of Jos and environs in north central Nigeria were conducted by visual and manual inspections from three data sources, which were later combined to form the fourth source. Positively skewed values are characteristic results of statistical analysis of the data. Numerical values of lineament frequencies in the various class intervals range from zero for relatively stable environments to sixty-three where intensity of emplacement of the rock bodies were relatively high. Major lineament trends were found in conjugate NE–SW and NW–SE orientations. Main structural directions of the rose diagrams are the NE–SW, NNE–SSW and NW–SE and the structurally directions derived from 2D maps are aligned along NE–SW, NW–SE, N–S and E–W. These trends are consistent with the trends of the Nigerian Basement Complex and the Younger Granite complexes of Nigeria. The density and orientation of the fracture lines revealed areas of greater lineament development in the study area occurring over the surface expression of the Younger Granite complexes of Jos and environs intrusion and other rock units. This study is significant for evaluation of the geo-processes that generates stress and produces deformational effects capable of changing the shapes of the rock by fracturing, Joints with other linear structures being observed on the various rock units and understanding the patterns of structural trend in the Younger Granite complexes of Jos and environs in north central Nigeria.

Keywords: Density, Frequency, Lineament, Rose Diagram, Younger Granite Complexes.

INTRODUCTION
The Precambrian rocks in the study area are part of the Precambrian Basement complex of Nigeria which is made up of the migmatite-gneiss complex, Older Granite and the Younger Granite rocks. The main lithologic units in the study area include; granite-gneiss, migmatite-gneiss and Younger Granite rocks with well delineated geologic boundaries amongst others. The Precambrian Basement rocks have undergone polycyclic deformation thereby causing the deformation of both micro and macro structures as displayed on the field. Geologic structures in rocks that can be used as clues in determining the geologic history of an area include fold, fractures, foliation, dyke (Adedeji and Dare, 2015). Some of them are not deformational but are secondary structures developed during metamorphism of after the emplacement of the rocks. Linear features are usually good exploratory targets as they aid migration of fluids and host accumulation of minerals of economic importance. The Younger Granite complexes of Nigeria in which the Jos Younger Granite complexes are a part trend in an N–S belt with the ages of the complexes decreasing southwards. Rahaman *et al*., (1984) showed that major local magmatic activities were concentrated along ENE and WSW zones. The age pattern suggests that the parent magma was locally derived from several simultaneous high-level magma chambers connected to a common deeper source (Ike, 1983). Emplacement of these ring complexes were controlled by fracture systems in the basement (Rahaman *et al*, 1984).

Location and Geology of the Study Area
The study area is located within latitudes 9°00ᴵN – 10°30ᴵN and longitudes 8°30ᴵE – 10°00ᴵE and is part of the Younger Granite complex, north central Nigeria, covering an approximate surface area of 27,225 km^2 (Fig. 1). The study area is generally accessible and motorable, the availability of both tarred and untarred roads as well as footpaths provide good accessibility to the area and to the outcrops. The settlement pattern in the study area is both nucleated and disperse types. An outline of the geology of the Jos Plateau is dominated by plutonic and volcanic rocks, with the alluvium filled valleys as the only sediments, and the Crystalline Basement Complex (Fig. 1).

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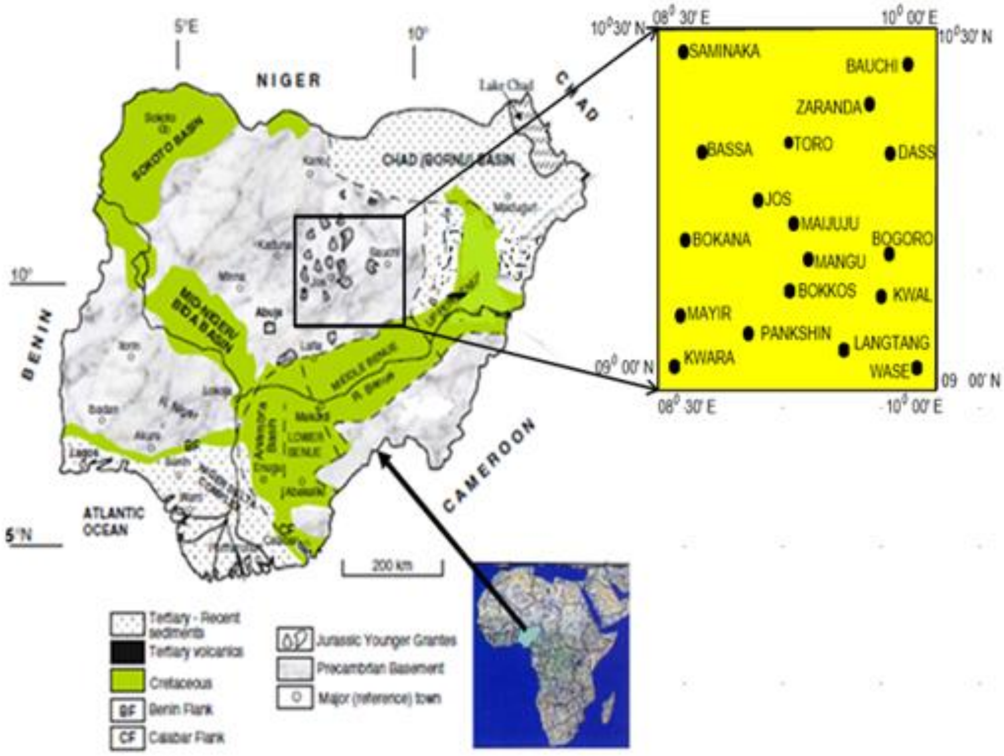

Fig. 1: Generalized Geological Map of Nigeria Showing the Study Area (Modified from Obaje, 2009).

The Basement Complex rocks of the study area comprises gneisses, migmatites, and granite gneisses. These rocks are believed to have been formed from migmatization and granitization of pre-existing gneisses (McCurry, 1989). The Older (Pan-African) Granites have a wide range of varieties which include intrusive granites ranging from the porphyritic biotite and biotite hornblende granites to the fine to the medium grained biotite granite. The geology of the Jos Plateau is dominated by Jurassic, non-orogenic Younger Granite complexes. About 50 complexes are found occupying an area of 8,600 km^2. The Younger Granite complexes trend in an N–S belt with the ages of the complexes decreasing southwards. Rahaman *et al* (1984) pointed out that major local magmatic activities were concentrated along ENE–WSW zones.
After the emplacement of the Younger Granites, there was periodic erosion during which the Jos Plateau was formed. The alluvium derived was deposited in river channels and became covered in the early Tertiary times by the volcanic episode that gave rise to the Older Basalts. These have been decomposed to clays and laterite. Later alluvium decomposition was followed by another volcanic episode which gave rise to the well-preserved cones and lava flows of the Newer Basalts (Buchanan *et al.,* 1971).

MATERIALS AND METHODS

Materials

The materials used in this work include both software and maps: the software are: Oasis Montaj version 8.4 (2015), rockworks (2017), ILWIS 3.3 (2005), surfer11 (2012) and micro soft excels (2016). The maps include: aeromagnetic, Satellite image, Drainage and their overlays with geological map.

Methods

Lineaments Analysis

Lineaments are surface expressions of subsurface deformation that reveal the hidden architecture of the basement rock. O'Leary *et al* (1976) defines lineaments as a mappable, simple or composite linear feature of a surface whose parts are aligned in a rectilinear or slightly curvilinear relationship which differ from the pattern of adjacent features and presumably reflects some subsurface phenomenon. Identification and analysis of lineaments from magnetic, satellite, drainage and combination of these sources were conducted by visual and manual inspection of each of the data and imagery on the same scale. Lineaments were identified and digitized on screen using the tools in global mapper and ArcGIS 10.4 software. Global mapper was used to georeferenced all the maps. Individual lineaments were analyzed for direction trends in the Rockworks 17 software. Rose diagrams were created from the lineaments maps and presented as directional trends on 15^o orientation class intervals in the same software environment. Individual lineament lengths were statistically analyzed and plotted on frequency distributions of lineaments frequency per lineament length class in ArcGIS 10.4 software environment. Lineament density was calculated for each section of cell of the source data using the total lineaments lengths contained within each unit section. The three sources of the lineaments (magnetic, satellite and drainage) were superimposed into a single map. Lineament density was calculated for each section of cell of the source data using the total lineaments lengths contained within each unit section. Nodes were determined at the central points of each of the sections in ILWIS 3.3 software for

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extraction of geographic coordinates and data file management of corresponding lineament density values. The resulting X, Y, Z data file was imported into Surfer11 (2012) software for contouring using Kriging interpolation algorithm. The interpolated density contours were exported from Surfer11 (2012) into ILWIS 3.3 (2005) for spatial projection. The frequency of the lineaments was plotted against the lineament length class in kilometers was display by the lineament density bar chart. The lineament density lengths of the bar chart were grouped into class intervals of one. The rose diagram shows the direction of the dominant lineament trend in the area of study and was organized into a bin sizes of 15°. A family of concentric circles provides scaled control for the number of fracture orientation values that occupy each bin size.

Lineament Density Maps
Lineament density maps display the distributions of the lineaments in two-dimensional maps. The area was divided into equal area grids of 81 blocks (9 columns and 9 rows). The number of lineaments in each grid were counted and recorded. A lineament that extended into another domain boundary was counted within the grid area extended into it. The numbers were assigned to the centre of each grid area and then contoured at appropriate intervals. The maps are shown as Interpolated contour pseudo representations of the lineament density maps.

RESULTS
Lineaments trends
The results of interpolated lineament length characteristics are extracted from aeromagnetic map (Fig. 2) and that of the satellite (Fig. 3) and that of the drainage (Fig. 4). The three overlaid (Fig. 5) was used to infer the structural trends in relation to the emplacement of the Jos Younger Granite Complexes and other rock units

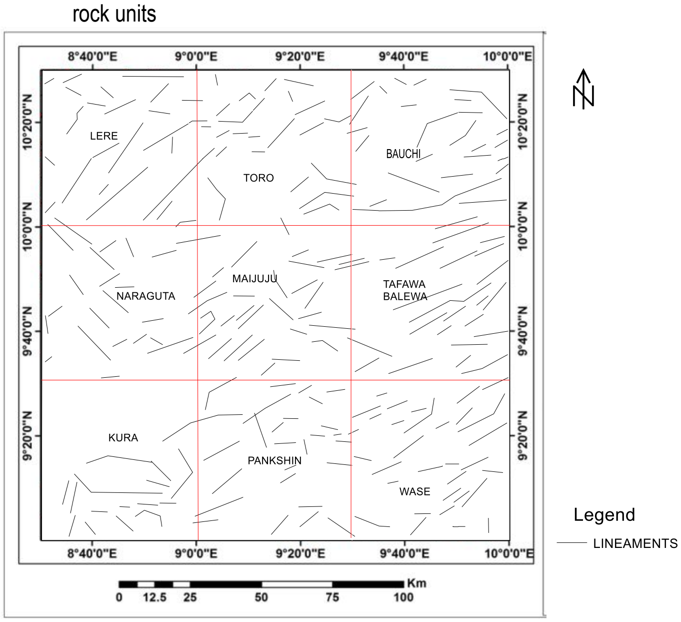

Fig. 2: Magnetic Lineament map of the Jos area and environs, north-central Nigeria

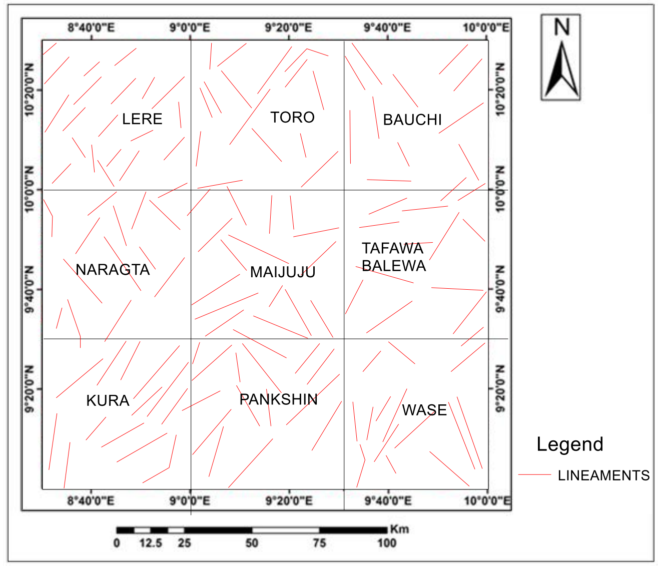

Fig. 3: Satellite Lineament map of the Jos area and environs, north-central Nigeria

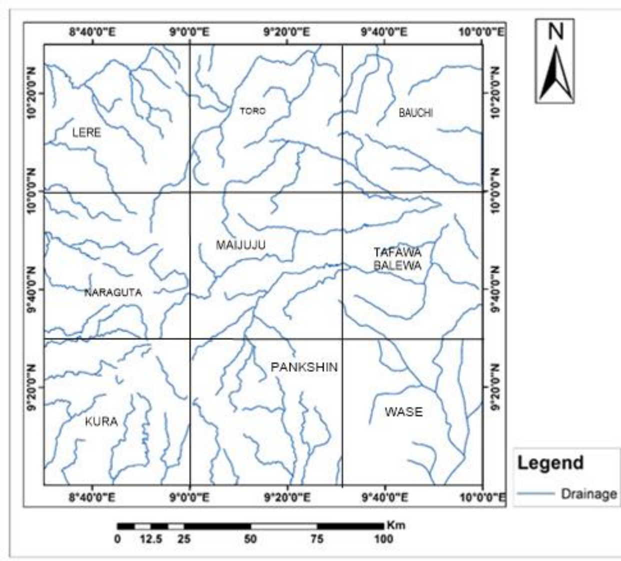

Fig. 4: Drainage Lineament map of the Jos area and environs, north-central Nigeria

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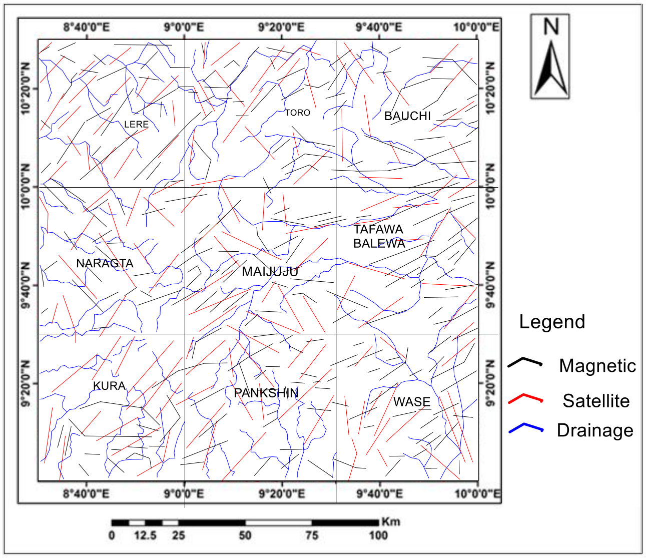

Fig. 5: Combined Lineaments map of the Jos area and environs, north-central Nigeria

The results from Table 1 shows total length of lineaments from the Magnetic map to be 2,302,476.30 km with an average of 12,791.50 lineaments per kilometre. The total length of the lineaments from the satellite image is 2,128,857.40 km with an average of 11,826.99 lineaments per kilometre. The total length of the lineaments from the drainage map is 2,768,061.60 km with an average of 15,378.12 lineaments per kilometre. The combined lineaments have total length of 7,199,395.30 km and average of 13,332.21 lineaments per kilometre.

Table 1: Statistical Distribution of the Lineaments

Lineament Source	Lineament Length Characteristics (km)					
	Sum	Minimum	Maximum	Average	Standard Deviation	Skewness
Magnetic	2,302,476.30	0.01	91,244.50	12,791.50	17,424.50	1.73
Satellite	2,128,857.40	0.02	86,129.40	11,826.99	16,757.99	1.89
Drainage	2,768,061.60	0.04	340,130.80	15,378.12	35,370.79	7.88
Merged	7,199,395.30	0.07	340,130.80	13,332.21	24,735.15	8.12

Lineament Density Bar chart

In Fig. 6 magnetic lineament density bar chart has the highest lineament frequencies of magnitude 21 at class 4. A lineament frequency of 1 was recorded at class 1 and 10 respectively, while class 9 did not record any lineament length frequency. Satellite bar chart of the lineament density shown in Fig. 7 is positively skewed. The class 2 has the highest lineament frequency value of 28; a lineament frequency of 1 was recorded at class 7 while class 6 did not record any lineament length frequency. Drainage bar chart of the lineament density (Fig. 8) is positively skewed. The class 2 has the highest lineament frequency value of 29; a lineament frequency of 1 was recorded at class 6. Combined lineament density bar chart in Fig. 9 produces numerical lineament frequency value of 63 at class 2. The lineament frequency value of 1 at class 10, while class 9 did not record any lineament length frequency value.

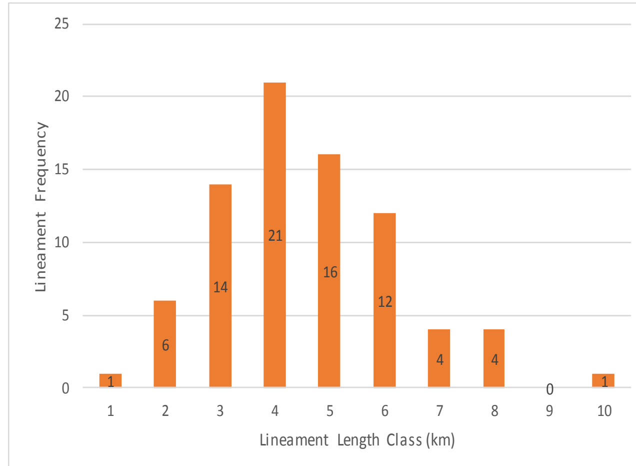

Fig. 6: Magnetic Lineament Density Bar chart of the Jos area and environs, north-central Nigeria

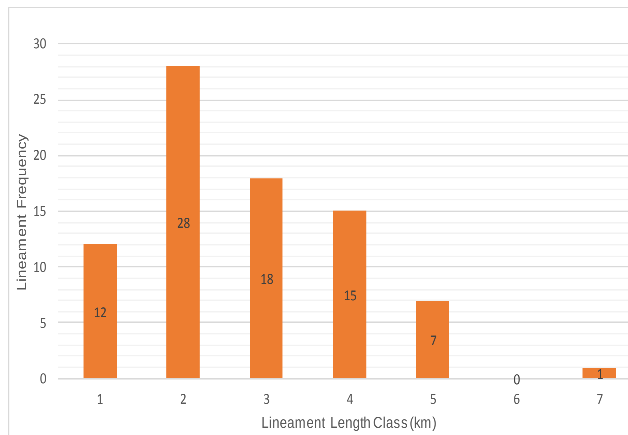

Fig. 7: Satellite Lineament Density Bar chart of the Jos area and environs, north-central Nigeria

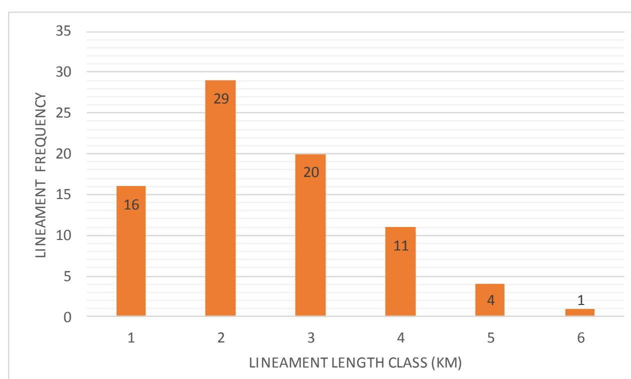

Fig. 8: Drainage Lineament Density Bar chart of the Jos area and environs, north-central Nigeria

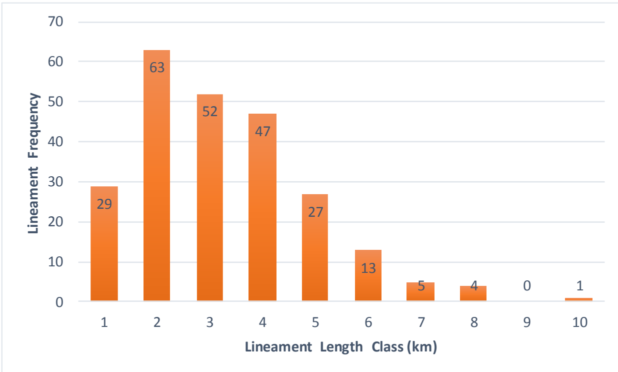

Fig. 9: Combined Lineaments Density Bar chart of the Jos area and environs, north-central Nigeria

Lineament Density Orientations and Rose Diagrams

Directional data extracted during analysis of the fractures are summarized on Table 2 and presented in rose diagrams in Figs. (10 - 13). Magnetic lineament density rose diagram (Fig. 10) produces five numbers of trends, one primary (1°) trend of N 55° E with one secondary (2°) trends of N 65° E, with one tertiary (3°) trends of N 90° E, with one quaternary (4°) trends of N 45° W and one pentagonal (5°) trends of N 7° E. Satellite lineament density rose diagram (Fig. 11) produces three numbers of trends which is one primary (1°) trend of N 45° E with one secondary (2°) trends of N 45° W and with one tertiary (3°) trends of N 5° W. Drainage lineament density rose diagram (Fig. 12) produces five numbers of trends, one primary (1°) trend of N 5° E with one secondary (2°) trends of N 85° E, with two tertiary (3°) trends of N 30° E and N 60° W with one quaternary (4°) trends of N 45° W and one pentagonal (5°) trends of N 75° E. Combine lineament density rose diagram (Fig. 13) produces five numbers of trends which are one primary (1°) trend of N 45° E with one secondary (2°) trend of N 85° E, one tertiary (3°) trend of N 5° E with one quaternary (4°) trends of N 45° W and one pentagonal (5°) trends of N 60° W.

Table 2: Lineament Orientation Trends.

Data Type	Number of Trends	Orientation Description				
		1°	2°	3°	4°	5°
Magnetic	5	N 55° E	N 65° E	N 90° E	N 45° W	N 07° E
Satellite	3	N 45° E	N 45° W	N 05° W		
Drainage	5	N 5° E	N 85° E	(a) N30° E (b) N 60° W	N 45° W	N7 5° W
Combined	5	N 45° E	N 85° E	N 5° E	N 45° W	N 60° W

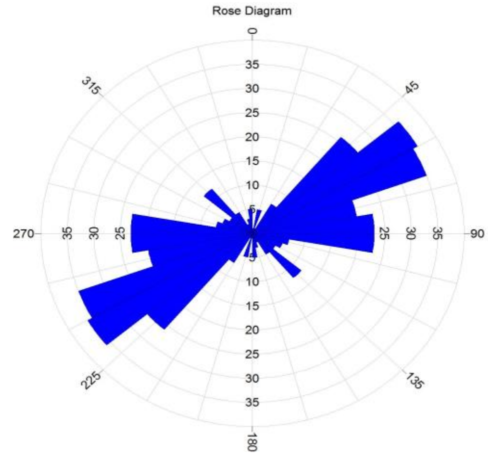

Fig. 10: Magnetic Lineament Rose Diagram of the Jos area and environs, north-central Nigeria

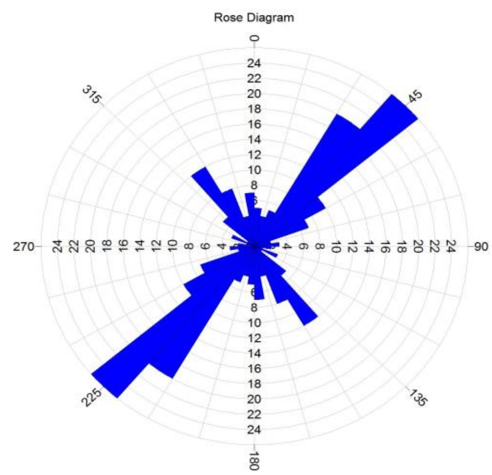

Fig. 11: Satellite Lineament Rose Diagram of the Jos area and environs, north-central Nigeria

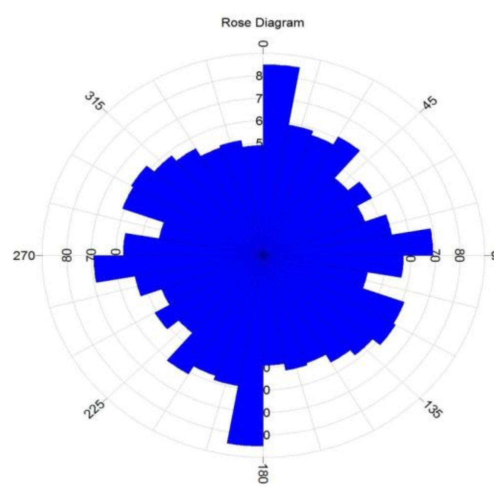

Fig. 12: Drainage Lineament Rose Diagram of the Jos area and environs, north-central Nigeria

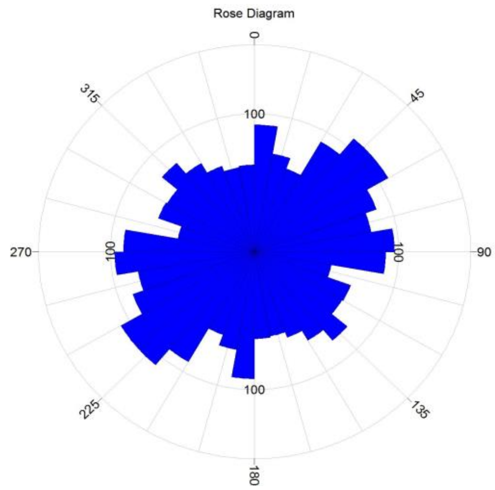

Fig. 13: Combined Lineament Rose Diagram of the Jos area and environs, north-central Nigeria

LINEAMENT DENSITY MAPS

The Magnetic lineament density map (Fig. 14) produces low density linear structures (blue colour) with values ranging between 0.5 and 3.0 and trending in a NE – SW direction around Tafawa Balewa, Pankshin and Toro with a NW – SE trend Naraguta and Lere respectively. With Kura sheet having a N-S trending. Intermediate values lineament density structures depicted in green colour have a frequency ranges from 3.0 - 6.0 sandwiches both the low and high lineament density structures within the entire map. High values lineament density features displayed in red colour ranges from 6.0 - 9.5 are observed around Maijuju and Tafawa Balewa both are trending in the NE – SW direction with a N – S trending direction observed in Kura. Others are found around extreme southeastern Wase and northern Bauchi and Toro respectively.

The satellite lineament density map (Fig. 15) produces low density linear structures (blue colour) with values ranging between 1.0 and 3.0 and trending along a NW – SE direction as observed at southeastern Kura and E - W direction as observed at Naraguta and Kura. Some of the low values structural lines sandwiches the intermediate lineament density structures as observed around Wase, Tafawa Balewa and Bauchi areas with the exception of Lere which is sandwiched by an intermediate density linear structure (green colour). Intermediate value lineament density structures (green colour) range from 3.0 to 4.5 and sandwich both the low and high lineament density structures within the entire map with the exception of Wase, Tafawa Balewa and Bauchi which are sandwiched by low density linear structures (blue colour). High values lineament density features are displayed in red colour ranges from 4.5 - 7.0 and was displayed in red colours.

The drainage lineament density map (Fig. 16) produces low density linear structures (blue colour) with values ranging between 1.0 and 2.5 and trending in a NW – SE, N – S and E - W directions. Some of the low values structural lines sandwiches the intermediate lineament density structures as observed around Kura, Maijuju, Naraguta, Pankshin and Lere sheet. Intermediate values lineament density structures (green colour) have a frequency ranges from 2.5 - 4.0 sandwiches the high lineament density structures. High values lineament density features (red colour) ranges from 4.0 – 5.9 are observed around Maijuju, Naraguta, Wase and Bauchi both are trending in the E – W direction with a N – S trending direction observed around, Bauchi, Naraguta, Wase and Maijuju respectively.

The Combined lineament density map (Fig. 17) produces low density linear structures (blue colour) with values ranging from 1.0 to 2.5 and trend along a NE – SW and NW – SE directions as observed at Wase, Naraguta, Kura, Pankshin, Maijuju and Tafawa Balewa. Intermediate value lineament density structures (green colour) ranges from 2.5 to 4.5 and sandwich both the low and high lineament density structures within the entire map. High value lineament density features (red colour) range from 4.5 to 6.5 are observed around Kura, Wase, Maijuju and Bauchi.

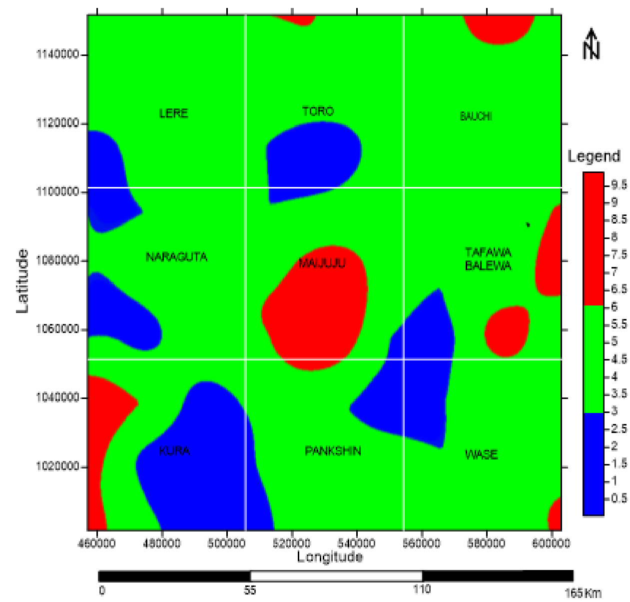

Fig. 14: Magnetic Lineament Density Map of the Jos area and environs, north-central Nigeria

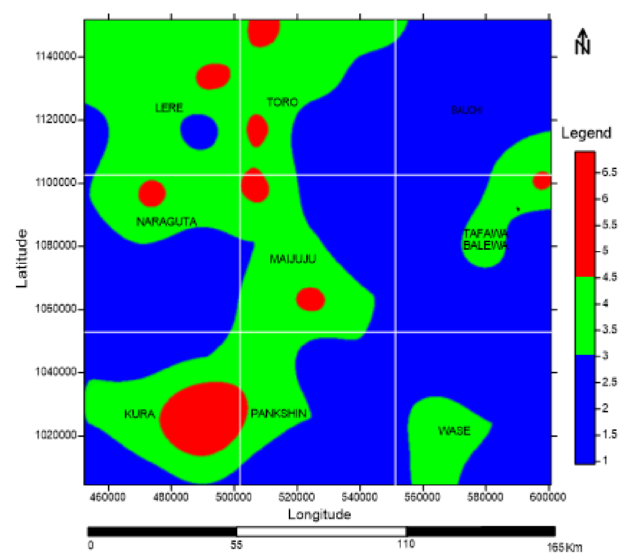

Fig. 15: Satellite Lineament Density Map of the Jos area and environs, north-central Nigeria

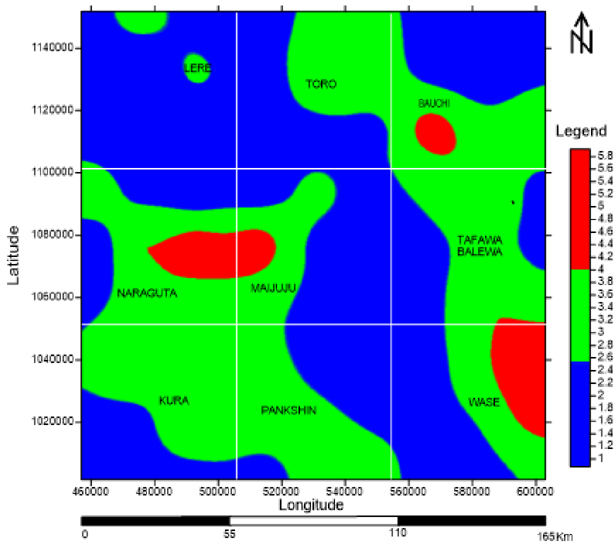

Fig. 16: Drainage Lineament Density Map of the Jos area and environs, north-central Nigeria

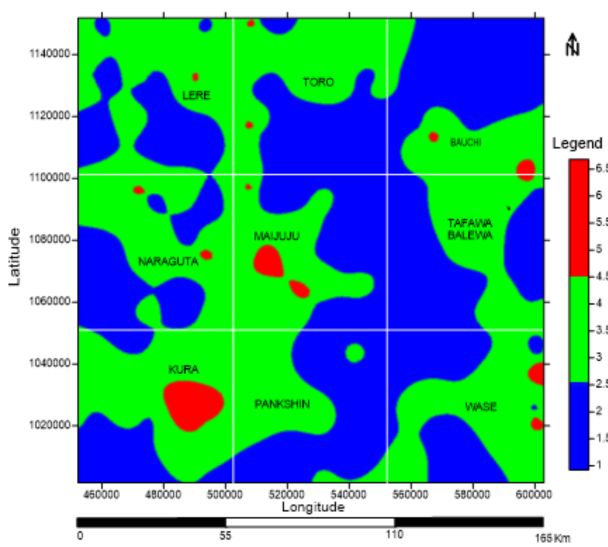

Fig. 17: Combined Lineament Density Map of the Jos area and environs, north-central Nigeria

DISCUSSION

The subsurface structural trends and rose diagrams (Figs.10 - 13) in the study area extracted from magnetic, satellite, drainage and combined data types were oriented along NE–SW, NW–SE, NNE–SSW, NNW–SSE, ENE–WSW and WNW–ESE directions respectively. Similarly, Nwokocha (2016) revealed the dominant structural trends in the Younger Granite complex to be in NW–SE and NE–SW directions. Opara *et al* (2015) showed linear features identified in the Naraguta area revealed principal trend directions in the NW–SE, NE–SW, N–S and E–W directions with the N–S trend been dominant over Naraguta area, north central Nigeria. The structural framework of the Nigerian Basement Complex is dominated by the NE–SW lineaments (Ajakaiye *et al.,* 1991; Megwara and Udensi, 2014). The NE–SW trend could indicate the Romanche and Chain fracture zones. Goki *et al*, 2020, stated that the multiple tremors of Nok and Chori villages in the north and northwest of Kwoi of 2016 and the Mpape Abuja tremor of 2018, all have their epicentres plot along an extrapolated trend that coincides with the Chain Fracture Zone of the North Atlantic. The NE–SW trend reflects the younger tectonic events, because the younger events are more pronounced and tends to obliterate the older events. The E–W, NW–SE, and N–S, reflect the old and deeper tectonic trends. The ENE-WSW orientation arises from an ancient zone of weakness in the basement oriented in the E-W direction that got reactivated during the late Phanerozoic plate tectonic episode (Ojo, 1990).

The 2D maps in the study area are aligned along NE–SW, NW–SE, N–S and E–W. This result is almost the same with the work of Alkali (2013), He confirmed that the structural directions derived from 2D maps were aligned along NE–SW, NW–SE and ENE–WSW around Kagoro Younger Granite rocks in north central Nigeria. The lineaments drainage map of the study area reveals that the study area is highly active tectonically because lineaments were mapped all through the study area with low to high density. Several lineaments align in the same direction with the drainage pattern. This also corresponded by fractures trending in the NE–SW direction indicating an older tectonic event; this infers that the streams and rivers are tectonically controlled. Drainage pattern here shows a dendritic pattern suggesting that the rock in this area is proned to erosion and weathering (Onyewuchi, 2011).

The lineaments extracted from landsat imagery revealed four groups of linear features in the NE–SW, NW–SE, N–S and E–W with the dominant trend in the NE–SW direction. The study area revealed that several lineament traces were observed where basement outcrops are closer to the surface. It is also observed that most complexes outcrop seen on the satellite map trends NE–SW, NW–SE which is in line with the structural trends of north central Basement Complex of Nigeria.

From the lineament density maps of the study area, the major fracture directions are NE– SW, NW–SE and minor fracture trends N–S and E–W. There is marked correlation of the features/locations of areas of high lineament densities with the known locations of the Younger Granites Ring complexes. Alkali 2013 observed that the surface expression of the Kagoro intrusion is revealed by high lineament density. The lineament density locations are of great importance for groundwater exploration, mineralization targets, rocks quarrying and structural interpretation (Okeke, *et al.,* 2019). The lineament density maps showed the spatial distribution of the density of lineaments in the study area. High lineament densities were also observed in areas where the basement rocks outcrop is 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 stresses. This correlation is an indication that the emplacement of the Younger Granite Ring complexes may be associated with epeirogenic uplift. The high lineament densities in these areas suggest that the areas are strongly deformed mainly as a result of basement uplift. Obaje 2009 reported that 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.

Conclusion

Three data sources of lineaments were identified and mapped. These were overlaid to form the fourth source of lineament data.

Statistical analysis on the data produced positively skewed indices. Lineaments frequency values within the various class intervals range from zero in the environments where magmatic activity was relatively stable to sixty-three in the environments of major activity. Structure trends along the NE–SW, NW–SE and the ENE–WNW responded to both stress difference and orientation of the principal stresses. The NE–SW set is interpreted as belonging to fractures generated by tectonics activities. The surface expression of the Younger Granite complexes of Jos intrusion is revealed by high lineament density. Therefore, this study is expected to contribute significantly to the rock movement in the earth subsurface that generates stress and produces deformational effects capable of changing the shapes of the rock by fracturing, Joints and other linear structures being observed on the various rock units within the Younger Granite Complexes of Jos and environs in north central Nigeria.

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