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REVIEW ARTICLE

GEOLOGICAL INTERPRETATION OF LANDSAT IMAGERY OF NIGERIA'S HAWAL PRECAMBRIAN BASEMENT COMPLEX TERRAIN

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ABSTRACT

The Hawal Basement Complex is located in Nigeria's NE region. Satellite imagery used in this study covers longitude 12º 00' to 13º 30'E, and latitudes 9º 30' to 11º 00'N. The aim of the study is to decipher the regional geologic structures based on analysis and to determine the mineralization implications from the landsat lineament data. The total land surface area covered is about 23,674.88 km^2 and includes part of the north sector of Yola sedimentary Rift Basin. The data consists of LANDSAT TM and SPOT XS scenes collated as mosaics. The imagery was monoscopically studied. Classical aerial imagery interpretation techniques of mapping lineaments and tracing regional geological boundaries were used. A total of 368 lineaments were mapped and analyzed using multi-graphical analytical techniques. The results are presented as isolinear contour maps (isodensity and lineaments intersection maps). The isodensity lineament maps show two main areas of lineament concentrations, namely Shani area lying westward and Michika-Mubi area to the east. Reasons advanced for the preponderance of lineaments in parts of the study area are the combined effects of isostatic basement uplift and lithospheric stretching during the formation of Yola Rift and Chad Basin respectively, which caused large scale crustal deformations. Also, Precambrian and Cenozoic magmatic activities that caused emplacements of older granites and basaltic bodies respectively in the area contributed to fracturation of the crust. Fewer lineaments are observed over the sedimentary Rift zone and this is attributed to masking effect of the sediments on basement fractures. The lineament intersection map shows a prominent NE-SW zone of highest intersection which is parallel to the general flow direction of the Hawal River. Prominent lineament directions are N-S (0-20º), and NE-SW (40º- 60º), which are Pan African Orogenic directions. Aerogeological studies of this type are important in national economic development.

KEYWORDS

Landsat data, deformation, lineaments, basement complex, Pan African Orogeny

1. INTRODUCTION

The Hawal basement is the northeastern segment of the Nigeria crystalline Basement Complex. The study area is located within the latitudes of 90°00′ and 11°00′*N* and longitudes 12°00' and 12°00'E (Figure 1), and is about 23, 674.88 km^2 in area. In developing countries of the tropics such as Nigeria, geological mapping of terrains is made difficult by ruggedness, weathering and sometimes thick vegetation. Remote sensing data gathering contains useful and low-cost environmental information, which can be extracted, analysed and utilized for economic development of the society. Such information is useful for basic geological mapping, identification of geologic structures, and mineral resource exploration. The satellite imageries used are indexed as BIU SHEET (No. 37), MUBI SHEET (No.38), and YOLA SHEET (No 48). The imageries are in the form of 1^0 by 1^0 sheets. The satellite imageries consist of both LANDSAT TM and SPOT XS scenes collated as mosaics (Figure 2). The imageries were acquired in January 1993 and November 1994, which are dry season and sunny months in Nigeria. They are published as false colour composites on a scale of 1:250, 000, or in digital form on compact discs.

This study sheds more light on the geology of Hawal Basement Complex. The study can also provide a regional structural framework on the massif of Hawal, by indicating the zones of anomalous lineament density and intersections. Diverse minerals and their structural controls with proven geological data can be identified through studies of photogeology (Abdullah, et al., 2011; Masoud and Koike, 2011; Raj and Prabhakaran, 2017). The lineament studies are particularly important because their distribution in space and their density can be used to infer the prospective zones for groundwater exploration, mineral exploration and geotechnical work as well as the emergent general lineament trends within the tectonic Nigerian Basement Complex (George et al., 2021; Umoh et al., 2022).

2. GEOLOGY OF THE STUDY AREA

The study area is bounded by Cretaceous Sedimentary Basins (Figure 1) with the Chad Basin to the north, the Gongola Basin to the west and the Yola Basin to the south. The oldest crustal material as observed from field work are mafic xenoliths and amphilolite fragments preserved in migmatites and gneisses and are probably of Proterozoic age (Dada, 1998). These latter groups of rocks are the most widespread, occupying mostly low elevations and are next in age to the xenoliths. The migmatites and gneisses are deformed into folds, faults, foliation and shear zones along NW, NE, N-S trajectories. The Pan African deformational directions are NE, N-S, with a reactivation in the NW direction in places. Pan African granites were injected into the metamorphic rocks during a widespread orogeny (750 ± 150 Ma). The existence of mylonite along fault zones in

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some localities shows the area is part of exhumed crust. The area lies close to Cameroun Republic, and Mesozoic to Cenozoic basalts of the Cameroun Volcanic Line are found as outcrops in the in area. A major outcrop of the basalt is found at Biu. Sedimentary rocks found are shales, clays, limestone and sandstones. Alluvial sands and gravel are restricted to river valleys.

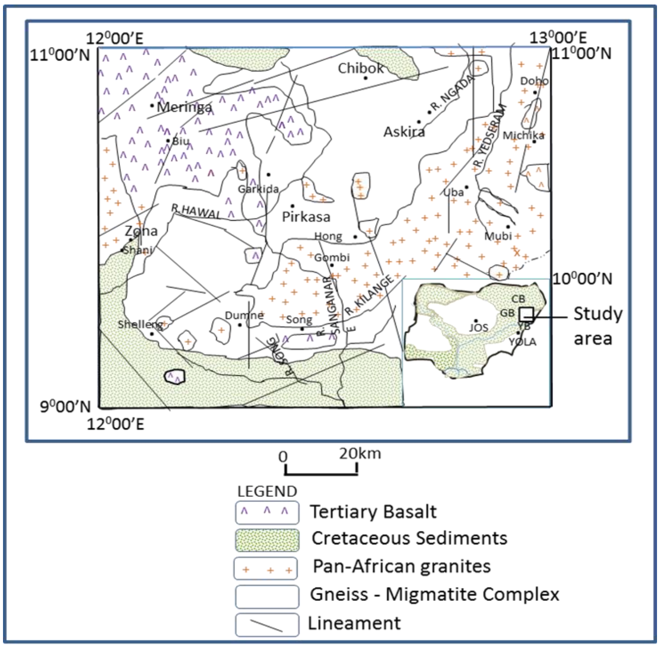

Figure 1: Geological map of study area (adapted from geological map of Nigeria by GSN, 1985, 1994).

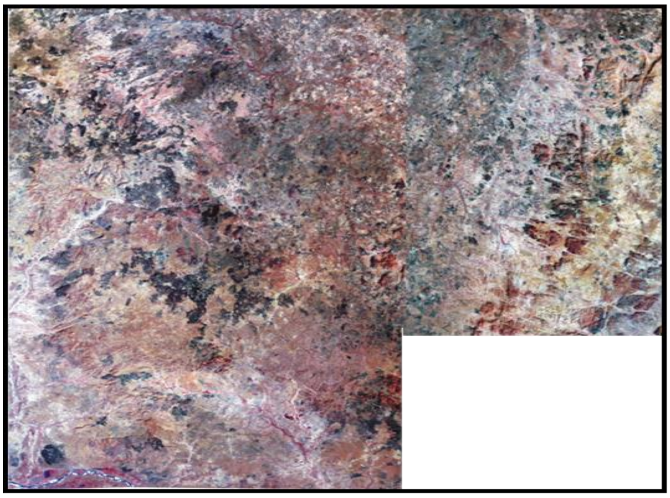

Figure 2: Satellite imagery of study area.

3. Methodology

The satellite imagery was monoscopically studied following classical aerial imagery interpretation techniques (Barrett and Curtis, 1976; Gardener and Miller, 1977; Drury 1987). A transparency was superimposed on the imagery against a light–table and major structural features (lineaments) and stream channels were identified and mapped. The lineaments represent faults, fractures, shear zones, regional foliation, trends of hills and valleys etc. Care was taken to ensure that straight lines that appear on the imageries due to 'tilling' (since they are mosaics) were not interpreted as geological lineaments. The interpretations are mainly structural in nature as lithological boundaries or contacts are difficult to ascertain because of image resolution problem (resolution is 30 m). The interpretations were guided by available maps, publications, reports and field work. Figure 2 is a reproduced copy of satellite imagery of the study area.

Three hundred and sixty-eight (368) lineaments were mapped (Figure 3) and their trends determined. The resulting lineaments were subjected to some multi-graphical analytical techniques. These are in the forms of histograms and isolinear contour maps. The isolinear contour map presentation follows the work (Odeyemi et al., 1999). This is because where the density of lineaments is high and orientations are diverse, the data in raw form make little sense except after subjection to some quantitative treatment and given adequate graphical presentation. This allowed for easy correlation of the lineament data with observable structural, lithological, petro-tectonic and geophysical phenomenon. It is also a useful tool on Geographic Information System (*GIS)* studies where contour lineaments data may be overlain on similar geophysical, hydrogeological (groundwater flow, drainage density contours, borehole contours) or mineral map in order to determine if there is any correlation or not between data sources.

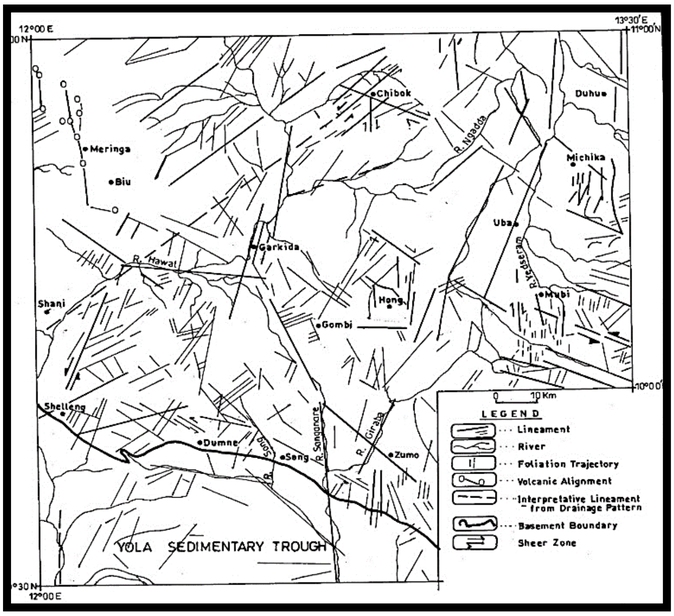

Figure 3: Satellite lineaments map of Hawal Basement Complex.

The isolinear contour maps consist of isodensity and lineament intersection maps. The prepared lineament density contour map was prepared by dividing a transparent overlay into equal area of size, 2.0 cm. The overlay was placed on the satellite lineament map. The number of lineaments within each grid was counted. The choice of the 2 cm grid was considered adequate as the resulting contour map compares favourably with satellite lineament map. A lineament that extends across a domain (grid) boundary was counted within every grid area crossed. The numbers were assigned to the centre of each grid and contoured. For the lineament intersection density contour map, the intersections were marked on a gridded overlay. The numbers of intersections within the grids were allocated to the centres and contoured in the same way as for the lineament density contour map. The contouring was done using version 7.0 SURFER software programme.

4. Interpretation of Satellite Data

4.1 Analysis of Histogram Lineament Data.

In the histogram (Figure 4) the prominent lineament trends are N- S (0-20°), and NE –SE (40°- 60°). The N-S and NE-SW lineaments are products of late and earlier Pan African deformational trends respectively. The N-S deformational direction in the Nigerian basement is defined by foliation and is the emplacement direction of the Pan African granitoids (750 ± 150 Ma). In the central zone of the study area (over Hong) the Pan African granites are emplaced N-S (Figure 1). Towards the east basaltic bodies are emplaced N-S between Duhu and South of Mubi. A number of major fluvial channels namely Rivers Yedseram, Ngada, Sanganare and the upper course of Hawal river flow N-S. These rivers exploit weak zones of the basement defined by foliations, faults and shear zones to define their courses. The first author mapped N-S faults, zones and shear zones in Uba, Chibok and Michika. Also mapped are N-S residual magnetic lineaments in the southern (Adamawa) Basements of the study area indicating a continuity of the deformations between the two basement blocks (Bassey, 2007; Kasidi et al., 2008). Between Dumne and Song area several NE and N-S striking parallel faults which have been mapped by the (Bassey and Valdon, 2011).

The two areas lie in close proximity to the Yola Rift. The parallel faults are considered as the youngest generation of faults in the area based on the report (Hobbs et al., 1976). These authors opined that the youngest structures in many rifted regions are a system of parallel faults. In the present study the parallel faults are attributed to crustal stretching and isostatic uplift during the formation of the Yola Rift. Some of the parallel faults serve as controls to Rivers that are transverse to the E-W Yola Rift (see satellite lineament map), examples are River Song and River Sanganare. E -W (80º - 120º) lineaments are few in the study area. Some of them are parallel to the southern boundary of the northern boundary of the Yola Rift Basin. Some others are found within the Basin and are considered syn-tectonic lineaments of basement origin. The middle course of Hawal River (west of Garkida) is controlled by E-W fracture/fault zone. South of Hong, an E-W lineament occurs, which ground truthing investigation shows it's a depression. A radiometric survey of Hong area shows the area has E-W radiometric anomaly of intermediate radioactivity and underlain by migmatite –gneiss complex (Bassey and Unachukwu, 2019). It is considered as a basement related fault zone also.

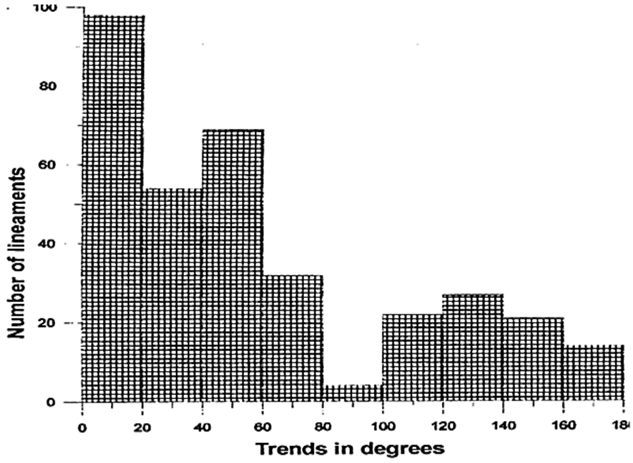

Figure 4: Histogram showing the number of lineaments with respect to the trends

There is a preponderance of the NE- SW lineament in the western half of the study area (Figure 3), with exceptions over Biu and Meriga areas where Cenozoic basaltic rocks mask some of them. The NE – SW lineaments are found between Shani town and Shelleng and were named Shani faults (Benkhelil, 1986). These faults are considered as part of the fault system that defines the NE trending Shani sub- Basin. The NE lineaments extend to east of Biu and Meringa and Chibok town. They are extensions of Kaltungo – Burashika – Zambuk ridge lineaments (Figure 5). The Kaltungo – Burashika – Zambuk ridge lineaments are basement shear zones (Maurin et al., 1986). The Kaltungo shear zone translates into kaltungo fault where the Pan African granite inlier is dextrally deformed. Bassey used magnetic, satellite, physiographic and field data over Chibok to demonstrate that the NE lineaments over Chibok are part of continental extensions of oceanic fracture zones namely Romache, Chain and Charcot (Bassey, 2006a). Similar observations were made (Benkhelil and Robineu, 1983). The fracture zones control the Benue Rift. NW- SE lineaments are found towards the west of the study area over the towns of Mubi, Michika and Duhu. The lineaments extend through to Hong, Garkida and Chibok. Part of the north boundary of the Yola Rift follows this trend. It can be inferred that this boundary has been geomorphologically formed by exploitation of NW-SW planes of weakness in the basement. Several faults have been mapped by Bassey between Song and Dunne which strike NW (Bassey, 2006b). Some of the NW deformations have also been observed as shear zones in Song, Dumne and Chibok by the same author.

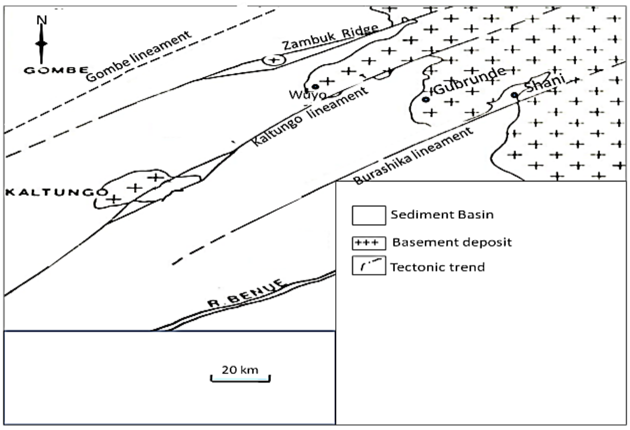

Figure 5: Sketch map showing Kaltungo, Burashika and Zambuk lineamentsin Upper Benue Trough (Maurin et al., 1986).

4.2 Analysis of Isodensity Lineament Contour Map

This map is shown in Fig.6.Prominent trends are NE, NW, N-S, and E-W. The 2-D isodensity lineament contour map shows peak regions to the SE of Song town in the south, Shani – Shelleng zone in the west, and Mubi – Michika zone in the east. These zones have lineament density contour values between 12 –20 per grid size of 5km^2. The highest peak is in Mubi area with 20/grid. Southeast of Song the NW trending isodensity lineament anomaly is attributed to the magmatic emplacement of the Tertiary basalt (Figure 1). Song basalts belong to Cenozoic magmatism of Cameroon Volcanic Line (CVL). Benkhlil described the Song basalt as aligning along N135º direction (Benkhlil, 1986). He stated that the emplacement of these basalt and other basaltic bodies in the Upper Benue Trough is directly controlled by basement structure. Field work has revealed a preponderance of NW foliation and shear zones in Song area within the migmatite gneiss complex (Bassey, 2006b).

For foliation and shear zone graphics in song area. Over Dumne is another anomalous zone of lineaments with a peak of 14/grid. The anomaly trends NW, aligning with Song anomaly indicating possible petro-tectonic relationship. Kwache and Ntekim mapped petro – structural features such as mylonite, pegmatite dolerite, aplite and quartz veins in Dumne area (Kwache and Ntekim, 2015). They also reported NW fault zone with Baryte mineralization. Cenozoic basalts are also found in Mubi-Michika to the east (see geological Map). This area also lies along the CVL. A group of researchers described rocks of Mubi area as consisting of high – k-calc-alkaline granitoids (Vandi et al., 2019). It can be asserted that the evolution of these rocks can be attributed to thermo-tectonic period of faulting, uplift, cooling, fractionation, and high-level magmatism during the Paleo-Proterozoic. The high density of lineaments in this zone can be ascribed to the aforementioned factors.

The NE trend of lineament density anomalies over Mubi and Michika is in consonance with the trend observed and reported by Ananaba and Ajakaiye in their analysis of satellite imagery over Nigeria north of latitude 8º (Ananaba and Ajakaiye, 1989). Over Shani-Shellen area in the west, the lineament density has a peak value of 18per grid with a trend of N – S, which is parallel to the Gongola Valley, west of Shelleng, (see Fig.1). Benkhelil reported that the lower Gongola River course (between Shani-Shelling areas) is guided by N-S trending faults (Benkhelil, 1986). This author also observed striking N-S alignment of volcanic hills of Biu Plateau with the said faults. North of Shani is a sparse anomalous zone (about 14 per grid). The paucity of lineaments here is attributed to the masking effect of Biu lava flow. Proximal to this area is N-S anomalous zone which is caused by some N-S tributaries of Hawal River. To the east of this is another marginal zone of low-density lineaments, which is coincident with Chibok lineaments. Between Garkida and Uba is a zone of relatively few lineaments stretching west to east with a contour peak varying between 12-14per grid.

This zone is underlain mainly by migmatite-gnesis complex with very few intrusive rocks, hence its relatively low lineament density. The west to east trend of lineaments correlates with the Chad Basin- Basement boundary (see Geologic map of Figure 1). In the central part of the map lies another zone with lesser concentration of lineaments bounded by the towns of Garkida, Gombi and Hong. Intrusive rocks are few in this region also. Between Hong and Gombi is a zone of low-density lineaments (4-8 per grid). From mapped data, this area is an area of polyphase deformation of the migmatite –gneiss complex, intruded by Pan African Pegmatitic granites. The emplacements of these granites follow NE, and N - S foliation directions. Also there are multiple directional orientations of brittle, planar, ductile and linear structures in the area (Yusuf et al., 2019; Bassey and Udinmwen, 2019).

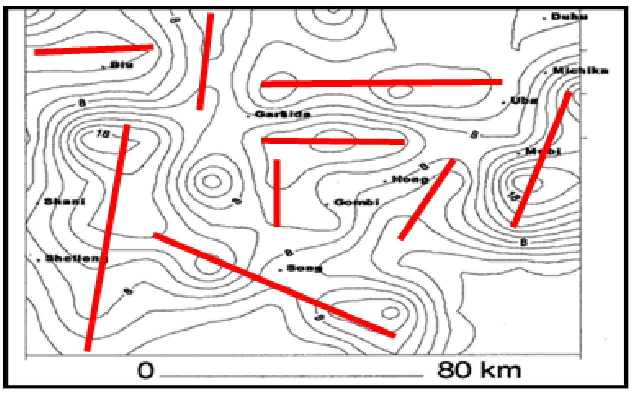

Figure 6: Isodensity lineament contour map

4.3 Lineament Intersection Contour Map.

This map is shown in Figure 7. The major zones of lineament intersection contour map are the central zone, Mubi zone and Michika zone. There is a close similarity between the lineament's intersection contour map and the isodensity lineament contour maps. However, the lineament intersection contour map has a central zone of high anomaly. Other zones of high anomalies are over Michika and Mubi to the east. Analyses of these three zones were done as they are the most significant. The central zone stretches NE with a NW arm. These two directions are directions of flow of River Benue to the north of Yola (Figure 8). This indicates that the R. Benue though flowing through a Cretaceous sedimentary cover (Bima Sandstone) is structurally controlled by deep seated basement conjugate structures. This observation was earlier made (Bassey et al., 2012). The NE Shani faults earlier discussed are extensions of Burashika and Kaltungo lineaments into the study area (Fig.5). These intersect with the N-S Gongola River faults and the NW structures (Figure 9) that control the Song basalts, intersections of these structures generate the high density lineament anomalies. The sketch in (Figure 9) illustrates lineament orientations. Eastward in Michika – Mubi areas is the high density of lineament intersection, which is attributed to a combination of rock fabric (foliation) and emplacement of pan African plutons with the attendant fracturing of the metamorphic host rocks. The N-S orientation of the two peaks aligns with the flow direction of the major river (River Yedseram), generally speaking the lineaments trends of N-S, NE, NW are the. General speaking trends in the Nigerian basement complex according to (Ananaba and Ajakaiye, 1989).

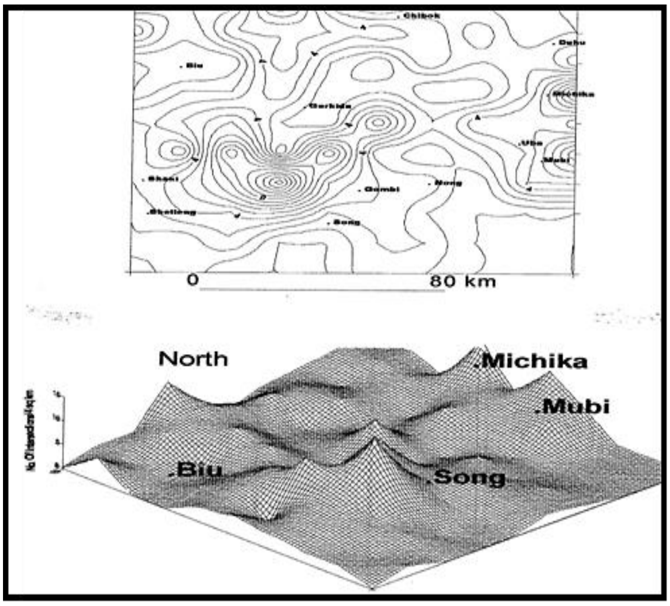

Figure 7: Lineaments intersection contour map of study area and its 3-D plot

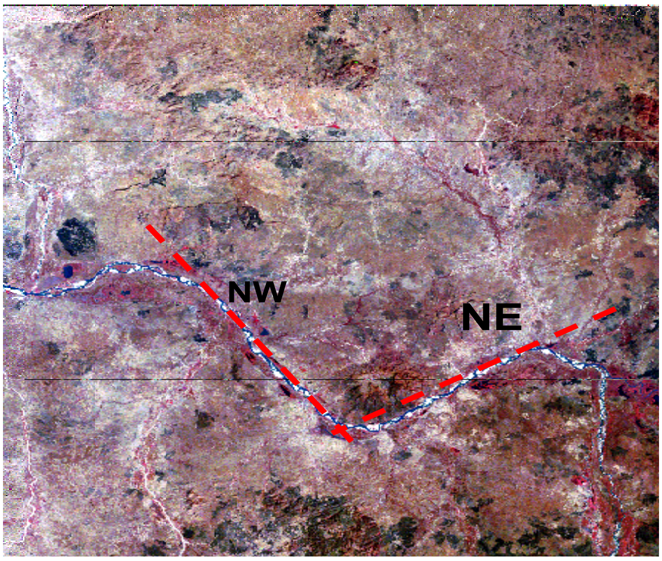

Figure 8: Satellite map of Upper Benue trough showing the NW and NE arms of the Benue River.

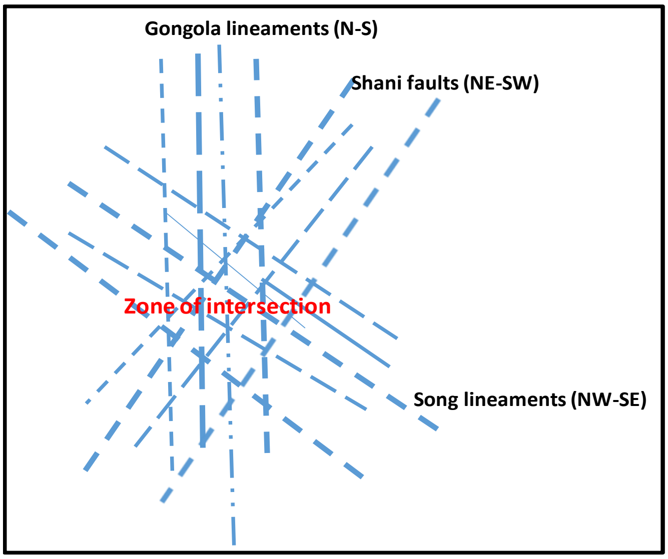

Figure 9: Sketch illustrating intersections of Gongola, Shani and Song lineaments which generate the anomalous zone.

4.4 Mineral Exploration Implications of Satellite Lineament Data.

Important ore fields have been discovered at intersection of lineaments and other structures (Evan, 2012). Ananaba and Ajakaije demonstrated tectonic control of mineralization in Nigeria using satellite data (Ananaba and Ajakaije, 1989). Regional structures influence localization of mineral deposits and mineral provinces. They are generated by plate tectonics and orogenic movements, igneous intrusions and major faults. Large scale regional faults or shear zones generate structural pathways for mineralization fluids to move from depths. Smaller structures like foliation, lineations, shear zones faults, fractures also play their parts. Therefore, qualitative and detailed study of satellite data can reveal large scale regional structures associated with mineralization. A ground follow up can lead to the discovery of small scale geological control on mineral deposits. In the present area of study some mineral deposits are found to be structurally controlled. Examples are Baryte in Dumne, Uranium in Michika, and in shani sub-Basin, manganese in Mubi, pegmatite in Mubi and Hong, rock crystals (quartz) in Dunme. Magnesite is found in Sakasimata near Gombi but may not be structurally controlled.

4.5 Barite in Dumne

Kwaache and Ntekim reported the occurrence of a barite vein (a mineral used in manufacturing of drilling mud for the oil industry) along a fault striking N70º within the granite and gneiss in Dumne (Kwaache and Ntekim, 2016). The vein is reported to be 5 m thick with an exposed length of 25m, lying at a depth of 9m. The said fault is part of the NE trending Shani-Shelleng basement marginal faults. The authors posited that the barite is of high quality for industrial use. Further exploration using lineament data expressed in this study may lead to more discovery of the mineral.

4.6 Rock Crystal (Quartz) in Dumne.

This was reported by Bassey and Valdon as detrital deposit originating from NE trending faults and joints in granite (Bassey and Valdon, 2011). The mineral is found as loose triclinic crystals in the weathered granite. The mineral is reported to occur in Mubi area also. Quartz is used in the manufacture of optical instruments, digital clocks because of its piezo-electric property.

4.7 Urarium in Gunchi, Michika, and in Shani sub Basin

Mohammed and Mohammed used radiometric survey to observe a radiometric high anomaly over a fault zone in Gumchi near Michika (Mohammed and Mohammed, 2017). They attributed it to Uranium occurrence. The mineralization according to these authors occurs at the intersection of NW, NE and N-S structures in granite. Features which define the fault zone, are silicified breccia, mylonite, cataclasite and shears. Gumchi is about 9km as the crow flies north of Michika. The major fault trend observed by the authors is N40ºW. The authors recorded a radiometric reading of 2000 cps (counts per second) using a scintillometer over the uraniferous fault zone against a background reading of 500 cps. The NW faults zone is part of the NW satellite lineaments over Michika which intersect N-S and NE lineaments as mapped in this study. Some researchers reported uranium occurrence in the fluvio-arkosic sandstone of Bima Formation, with a N65º trending Shani structural Basin (Suh et al., 1998; and Funtua, 1999). The Uranium primary deposit is reported by the first author to occur in the adjoining basement inlier of Gubrunde.

4.8 Manganese in Mubi

A group of researchers reported structurally controlled occurrence of manganese ore (and associated minerals) with a pegmatite vein striking N-S (Vandi et al., 2019). Manganese is said to occur as oxides of metallurgical grade which can further be processed for industrial use. The associated minerals are beryl, feldspar, barite, mica and tantalite. The first author has mapped a pegmatite vein of about 800m in length and 10m in width in Muvidi area of Mubi. The vein is hosted in granite and strikes NW. There are reports and documentations of occurrence of galena, chalcopyrite, and pyrite in the Mubi hills.

4.9 Magnesite in Sakasimta, Gombi

Nicodemus and Garba reported the occurrence of magnetite in the above town, proposing an epigenetic mangnesium-metasomatic model for the genesis of the magnetite from alteration of limestone from a proximal limestone inlier (Nicodemus and Garba, 2004). The lithologies of the area of Gombi are mainly granite and gneiss. The authors did not give any structural data on the occurrence of the magnesite.

4.10 Significance of Study in Pan African Deformational Geology.

From the study the emergent lineament density trends and directions are N-S, NE and NW. Oden prepared a tectonic synthesis of the main axes of Pan African Orogeny, reflecting the stress systems that operated at that period (Figure 10) (Oden, 2012). He reported that N-S orientation is the pure shear direction while NE-SW and NW-SE are simple shears 1and 2 respectively. The E-W indicates the direction of compression. These observations may be applied to the directional distribution of lineaments in the Hawal basement complex being a Pan African terrain, following Pumpelly's rule. This rule states that small structures are a key to mimic the styles and orientation of larger structure of the same generation. Within the small and large structures of the same generation may be shown to be related within the same area. From the synthesis it can be said that the stress systems initiated shears shears that propagated in fractures and faults as well as other planes of weakness that saw the emplacement of magmatic bodies along the N-S, NE, and NW directions. The planes of weakness also served as subterranean passages for mineralization fluids to move and form minerals. The compressive E-W direction resulted in formation of folds and probably other structures.

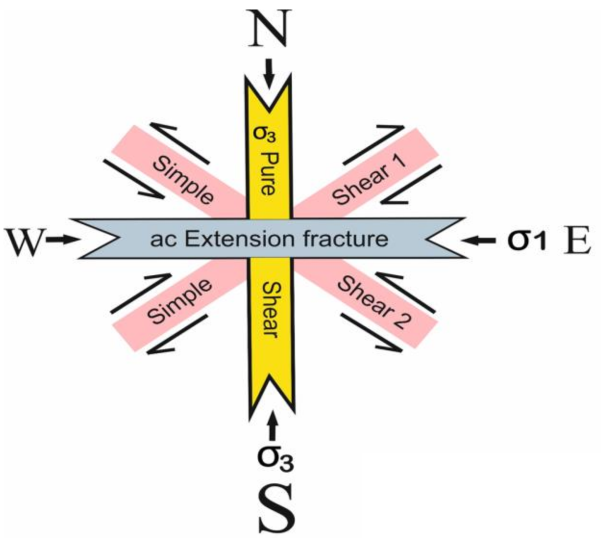

Figure 10: Main tectonic axes of the Pan African thermo tectonics (After Oden, 2012).

5. Conclusion

The study has shown the significance of satellite lineament study on the realization of the geology of Hawal Basement Complex. The study has also provided a regional structural framework on the Hawal Basement Massif, by pointing out the areas of anomalous lineament density and intersections. Mineralization of baryte, uranium, manganese, rock crystal and pegmatite as well as their structural controls with proven geological data has been found in the area. Moreover, it has also been realized that exploration for these minerals can be done using structural data from this work. Structural controls on emplacements of magmatic basic and acidic bodies have been discussed. The study has also identified the controls of lineaments on fluvial channels. Lineament studies of this type are particularly advantageous because at a glance their distribution in space and their density can be used to deduce prospective zones for groundwater exploration, mineral exploration and geotechnical work. The emergent lineament density trends in the N-S, NE and NW are the general tectonic trends in the Nigerian Basement Complex.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Human and Animal Rights

This article does not contain studies with human or animal subjects.

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