



INTERPRETATION OF AEROMAGNETIC DATA AND LANDSAT IMAGERY OVER THE NIGERIAN YOUNGER GRANITES IN AND AROUND KAFANCHAN AREA, NORTH-CENTRAL NIGERIA

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ABSTRACT

In this research the lineaments of the Kafanchan area in North-central Nigeria were investigated in order to explore the mineralization zones of the area. Aeromagnetic data over Kafanchan and environs within the Younger Granite Province, in the North-Central Nigeria were collated and analyzed. The aeromagnetic map of the area was interpreted both qualitatively and quantitatively so as to identify the nature of the magnetic sources and the trends direction in the study area. The trend of the Total Magnetic Intensity (TMI) map is predominantly in NE-SW. The First Vertical Derivative (FVD) Lineaments Map was also correlated with LADSAT lineaments map and both maps agreed in most areas. The study area is characterized by predominant magnetic lineament trend in NE-SW direction and subordinate E-W direction. The result also shows that the most significant structural trends affecting the distribution of these magnetic anomalies in the study area is in NE-SW direction. The TMI map indicates that there are three major mineralization zones in the study area. The high magnetization contrast in the NE and SE parts of the study area correlates with the migmatite-gneiss, biotite-granites, granites and basalts which are associated with high magnetic contrasts. Also, the high magnetization contrast in the NW part of the area correlates with basalt and the biotite-granite. However, the predominant low magnetization contrast observed in the western half does not correlate with the basic igneous rock.

KEYWORDS: mineralization zones, Younger Granite Province, magnetic sources, predominant magnetic lineament

INTRODUCTION

Geophysics, as its name indicates has to do with Physics of the Earth and its surrounding atmosphere. Gilbert's discovery which showed that the Earth behaves as a great and rather irregular magnet and Newton's theory of gravitation may be said to constitute the beginning of geophysics. Mining and search of metals date from the earliest times, but the scientific record began with the publication in 1556 of the famous treatise *De re Metallica* by Georgius Agricola, which for many years was the authority work on mining. The initial work in applying geophysics to the search for minerals probably was taken in 1843, when Von Wrede pointed out that the magnetic theodolite, used by Lamont to measure variations in the Earth's magnetic field might also be employed to discover bodies of magnetic ore. However, this idea was not acted on until the publication in 1979 of Professor Robert Thalen's book on the *Examination of Iron Ore Deposits by Magnetic Method* (Telford *et al.*, 1976).

The continued agitation in the demand for metals of all kinds and the enormous demand for petroleum products since the beginning of the 19th century have led to the development of many geophysical techniques employing equipment of ever-increasing sensitivity for the detection and mapping of subsurface deposits and structures. Since World War II there have been a lot of advancement as a result of rapid

development in the technology of instrumentation and the widespread application of the digital computer in the processing and interpretation of geophysical data (Telford *et al.*, 1976).

Geophysicists employ direct methods to measure small differences in the physical properties of the Earth. This allows them to probe the subsurface without having to drill a hole. For example, measuring the variations in the Earth's gravity or magnetic field of different places gives information on the density or magnetization of the subsurface rocks underground. Measuring the effects of an electric current transmitted through the ground gives clues to the apparent resistivity variation of the subsurface materials, a measure of how well or how poorly the materials and their fluids conduct electricity. Geophysical interpretations require integration with the knowledge of geologic mapping and topical studies, seismic data, hydrologic models, and drill hole information (USGS, 2013).

Knowledge of the geology of a region serves as the scientific basis for resource (Petroleum, solid minerals, ground water) exploration. Among the variety of rock types found in the Earth's crust many exhibit magnetic properties, whether a magnetization induced by the present day geomagnetic field or a remnant magnetization acquired at some time in the geological past, or a combination of both. Mapping the patterns of magnetic anomalies attributable to rock magnetism

has proved to be a very effective way of investigating large areas of geology at low cost per unit area (Adetona and Abu, 2013).

1.1 Location of the Study Area

The study area is located South-West of the Nigerian Younger granites province (i.e. Kafanchan area). This province occupies an area of about 22,000 km² in the central part of Nigeria from Latitude 8° 00' to 11° 00' N and longitude 7° 50' to 10° 00' E (Ajakaiye, 1974). Figure 1 is a map of Nigeria showing the younger granite province. Part of this province bounded from latitude 9° 00' to 10° 00' N and longitude 8° 00' to 9° 00' E was studied for this research. The actual area is shown by the location map, Figure 2. Which covers parts of Kaduna and Plateau states.

1.2 Geology of the Study Area

The study area is located within the younger granite province in the Northern Nigeria. The Younger Granite province

comprises of Precambrian to Lower Paleozoic Basement Complex rocks into which the Younger Granites suites are emplaced (Macleod et al., 1965). Basement rocks cover about three quarters of the Younger Granites province and consist of ancient sediments which are made up of granulitic gneiss, dioritic rocks, migmatites, granite-gneiss, older granites and granodiorites (MacLeod, et al., 1965; Oyawoye, 1964). Geologic map of the study area is shown in Figure 3.

1.3 Literature review

The history of geology is concerned with development of the natural science of geology. Geology is the scientific study of the origin, history and structure of the Earth (Boler, 1978). Throughout the ages, geology provides essential theories and data that shape how society conceptualizes the Earth. Scotsman James Hutton is considered to be the father of modern geology (Gohau 1990).

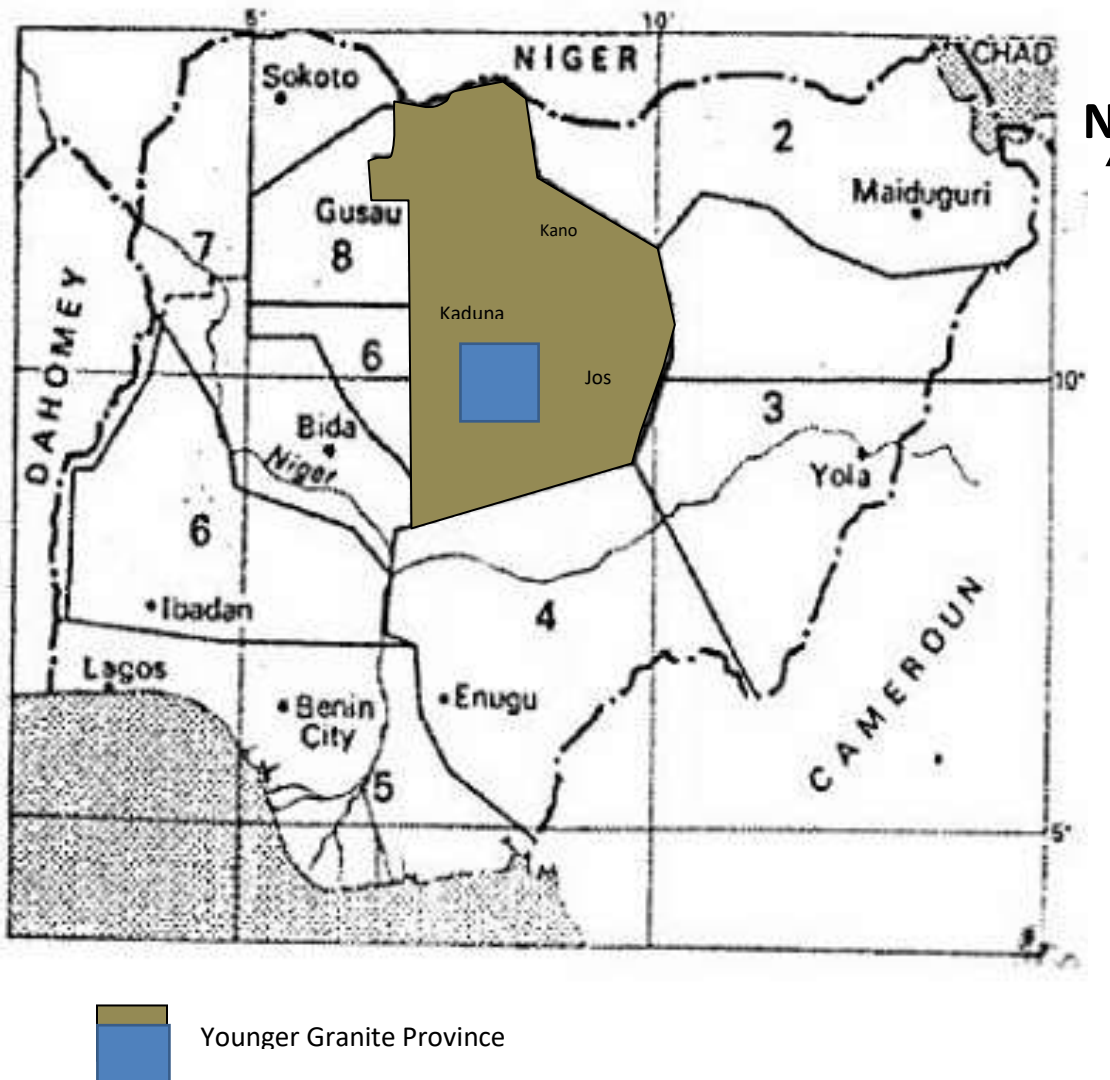


Figure 1.1. Map of Nigeria showing the Younger Granite Province and the study area (After Taofeeq et al., 2012).

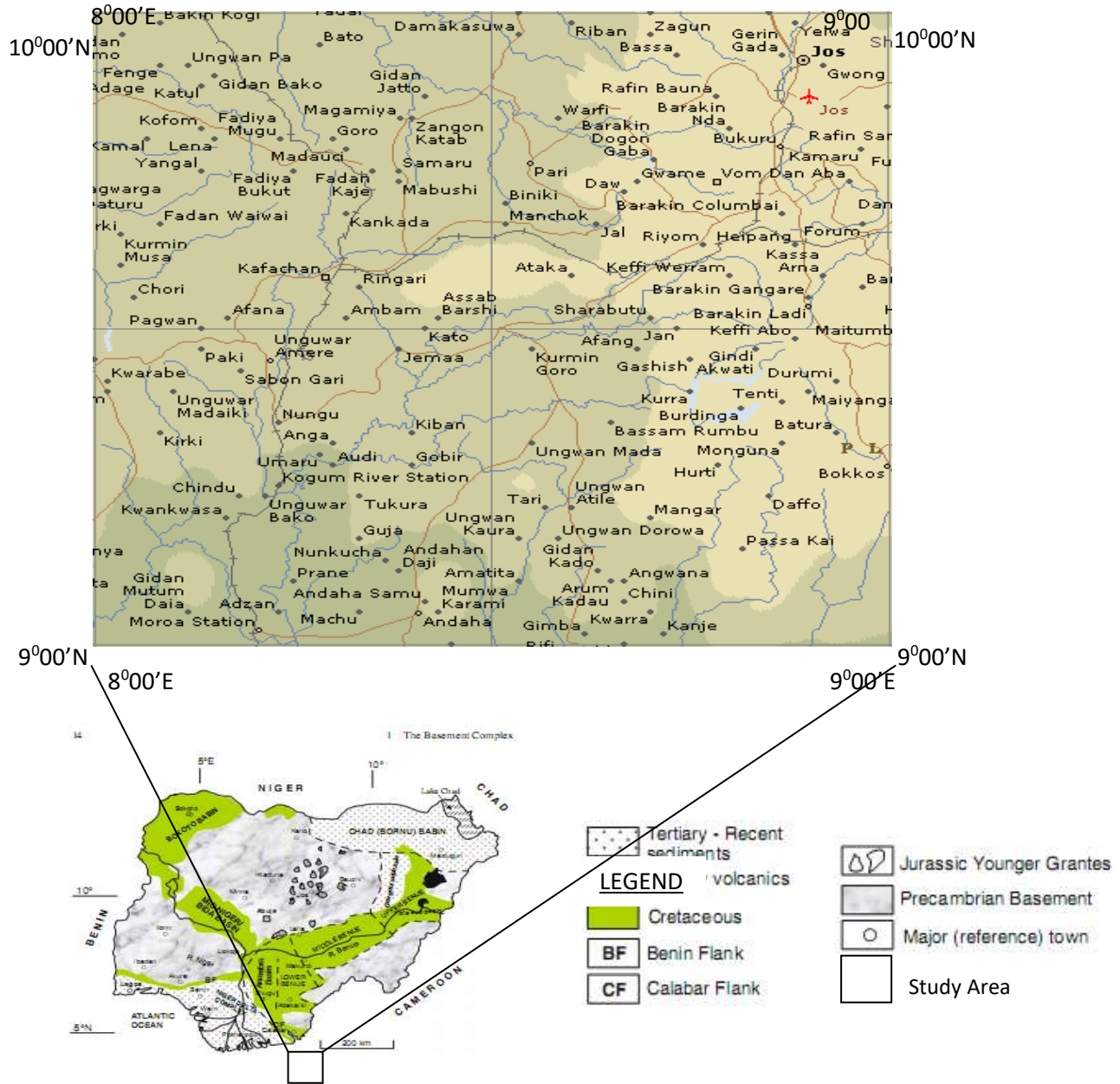


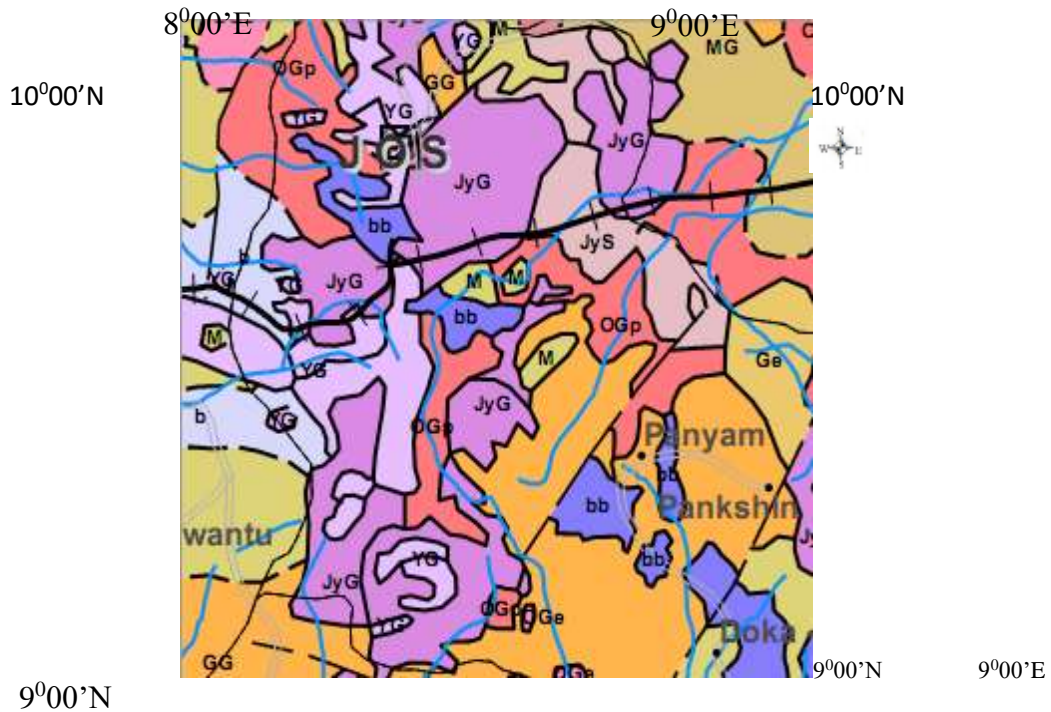
Figure 2. Location Map of the Study Area Modified After Geological Sketch Map of Nigeria Showing the Major Geological Components (After Obaje, 2009).

The first geophysical surveys were carried out successively in 1948 by Duprees, in 1951 by Shaw and in 1961 by Shaw and Cole for exploration purposes and covered an area of not more than 500 km² (Ajakaiye, 1974). Cassiterite (tin), columbite and other accessory minerals occur in buried river channels or deep leads which are cut into bedrock and subsequently filled with alluvial and or volcanic materials. Electrical resistivity method and magnetic method have been used to locate these buried channels thus enabling a reduction in the amount of exploratory drilling in the search for tin. One aeromagnetic map (sheet 168 Naraguta S.E) of a limited part of the province was published in 1963 by Canadian Aero

Service Limited under a Canadian technical assistance program in Nigeria. As a follow up to this work between 1964 and 1965, a United Nations Minerals Project and the British Overseas Geological Survey carried out an important geophysical study of the area covering about 350 km². Magnetic, seismic, resistivity and gravity techniques were used in the search of basalt-covered alluvial cassiterite (Masson-Smith, 1965). Gravity survey over the area revealed a broad regional anomaly ranging from about -30 mgal to about -65 mgal with a wavelength of 100 km and a northwest strike tending to be more negative towards the center of the province (Ajakaiye,

1975). The study also showed residual anomalies of up to 30 mgal which correlate well with the lower density Younger Granite complexes area isolated and extend to depths of from 3 to 12 km (Ajakaiye, 1974). Closely related to this was the determination of the densities of the more abundant rock types in the Younger Granite province. The density determinations involved rocks collected from various Younger Granite outcrops located all over the province. Aeromagnetic anomalies study across the area revealed the trend and lineament of the ring complexes indicating a relationship between these and the structural features of the Benue trough (Ajakaiye et al., 1982). An interpretation of aeromagnetic data across the central crystalline shield area of Nigeria which includes the Younger Granite province, revealed two groups of complexes petrologically different with a boundary that may be a fault line (Ajakaiye et al., 1983). The study also revealed magnetic anomalies striking NE-SW and that negative anomalies lie over most of the known ring

complexes and other intrusions. 2^{1/2} and 3-D modeling showed that the larger complexes extend to 12 km depth and the smaller ones to 6 km. They have nearly vertical sides and magnetization contrasts range from 0.3 to 0.5 Am⁻¹. Gravity and ground magnetic survey of the sub-basalts cassiterite deposit in Plateau State has also been carried out to determine basalts layers thicknesses. The survey revealed that basaltic layer thickness as obtained from gravity data range from 10 to 29 m and from magnetic, a range of 11 to 40 m. The basalt overburden depth from gravity ranges from 9 to 36 m with an average of 16 m while estimates from magnetic range from 14 to 21 m with an average of 17 m. (Kangni, 2001). Gravity study of Jos-Bukuru Younger Granite Complex revealed that the residual anomaly is characterized by both negative and positive values between -25 to +20 mGals(Taofeeqet al., 2012).



LEGEND

b	Younger Basalt	MG	Migmatitic Gneiss
bb	Basalt	M	Migmatite
GG	Granite Gneiss		
Ge	Quartz feldspathic granulite and gneiss		

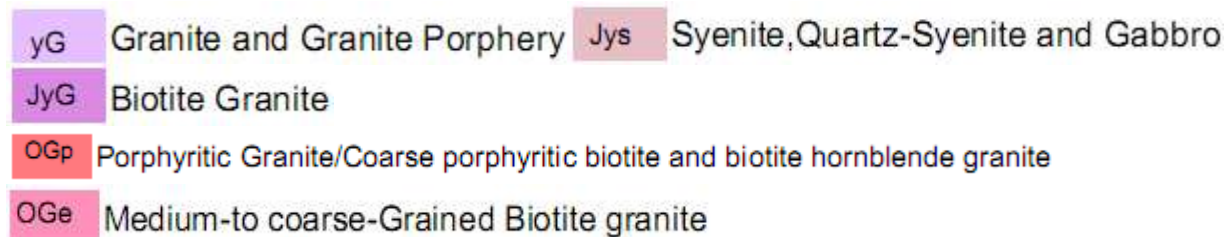


Figure 3. Geologic Map of the Study Area Extracted from the Geologic Map of Nigeria (NGSA 2005)

The negative values were interpreted as probably due to the intrusive younger granite rocks while the positive values may explain areas underlain by volcanic rocks. It also revealed two and one half models of the residual anomaly along profiles indicate depths up to 18.75 km for the plutonic rocks and 13.96 km for then volcanic rocks. The large depths were attributed to the presence of a large-scale fault associated with the Romanche fracture zone. The aeromagnetic data interpretation over the younger granite complex of northern Nigeria was also carried. The study revealed three major magnetic regions in the area; regions of positive anomaly which could be due to the rock rich in ferromagnetic minerals, regions of intermediate which are found to be lying over the differentiated basement complex and region of negative anomalies which could be due to acidic rocks. By spectral analysis the residual data revealed two magnetic sources at a mean depth of 0.17 km and 1.40 km for shallow and deep source respectively.

Alkali and Yusuf (2010), also made depth estimation of digitized aeromagnetic data of the western part of younger granite rocks of north central Nigeria. The result shows that the total magnetic intensity value ranges from 32670 to 33070 nT. The residual anomaly values fall between -110.4 to 76.1 nT. The fault attained depth maxima of 12.0 km, 13.0 km and 26.6 km.

3.0 Methodology

The aeromagnetic data set used for this study was obtained from the Nigerian Geological Survey Agency (NGSA) as a part of nationwide aeromagnetic survey conducted between 1974 and 1976. Nigerian land mass has been covered by aeromagnetic surveys to aid geologic mapping and to indicate areas of potential mineral resources.

The magnetic data were collected at a nominal flight altitude of 154.2 m along approximately N-S flight line spaced 3 km apart. The study area covers four $\frac{1}{2}^{\circ} \times \frac{1}{2}^{\circ}$ aeromagnetic maps published by the Nigeria Geological Survey Agency. The maps (sheets 167, 168, 188 and 189) were named as Kafanchan, Naraguta, Jemaa and Kurra respectively on a scale of 1:100,000. A constant value of 25,000 nT was subtracted from the Total Magnetic Intensity (TMI) values on the maps. The maps were digitized at 3 km interval thus generating on 19 x 19 grid (data) points on each map, and a total of 37 x 37 grid points for the study area. The grid interval was found to be adequate for analyzing crustal magnetic anomalies (Udensiet al., 2003). The constant value (i.e. 25,000 nT) was added to the digitized data to obtain the actual TMI values.

Aeromagnetic data are geophysical data acquired from aircraft that measure the subtle variations in the Earth's magnetic field

due to differences in the magnetic properties of the underlying rocks.

Computer methods have been developed to transform magnetic data into a merged map, where all the survey data are digitally merged (USGS, 2013). The total magnetic intensity observed over an area is a combination of a regional component and a residual component. The regional component is caused by deep seated structures, while the residual component is that due to relatively local sources (near surface structures).

The production of the total magnetic intensity (TMI) map of the study area was done by importing the digitized data into the Oasis Montaj (Version 7.01) software to produce a colour shaded map of the study area. The colour shaded map was subsequently interpreted and compared with the geologic map of the study area.

3.1 First Vertical Derivatives

The First Vertical Derivative (FVD) being among vertical derivative filter tend to sharpen the edges of anomalies and enhance shallow features. The vertical derivative map is much more responsive to local influences than to broad or regional effects and therefore tends to give sharper picture than the map of the total field intensity (Reynolds, 1998). Thus the smaller anomalies are more readily apparent in area of strong regional disturbances. In fact, the FVD is used to delineate high frequency features more clearly where they are shadowed by large amplitude, low frequency anomalies. They also tend to thin the widths of anomalies and also recognize or detect contacts/boundaries of geological bodies more precisely (Cooper and Cowan, 2004). The FVD is expressed as

$$FVD = (\partial T / \partial z) \quad (1)$$

The computation of the FVD in this study was performed in the frequency domain using the fast Fourier transform (FFT) technique. Accordingly, the digitized residual magnetic intensity values were transformed in to the frequency domain using the FFT. The Fourier transformed data was multiplied with the FVD filter (i.e. k^n , where $n = 1$ and k is the wavenumber) and subsequently inversely Fourier transformed in to the space domain to obtain the FVD values.

3.2 Landsat Lineament

Landsat is any of the several satellites used to gather data about the earth surface resources. The recent availability of specially enhanced satellite imagery has permitted a comprehensive study of the lineament within a study area. This study involves examining the prevalent orientations of linear physiographic trends and the relationship between these lineament trends and the structural geological lineament trend

and so also with the aeromagnetic lineament. A single scene of landsat enhanced thematic mapper was used to produce the lineament map, the rose diagram and the satellite image for the study area. The landsat lineament was overlaid on satellite image to derive some observations. Subsequently, the lineaments deduced from the landsat ETM+ and Aeromagnetic data were correlated. Moreover, the rose diagrams derived from the two lineament maps were correlated.

Lineaments (in landsat) can be defined as the linear physiographic features that suggest structural control of geomorphic development. Analyzing lineaments leads to evaluation of the structural control of an area. Correlation of lineament orientation suggests the structural geological control in different regions. Some of the interpreted lineaments correspond to known structures within the study area. These structures were first isolated and the rest were interpreted based on the existing knowledge of the structures in the area and additional fieldwork. The landsat lineament map was overlaid on the satellite image of the study area. Thus, to observed correlation of the landsat lineament with the known structural geological features.

3.3 Lineament Analysis

Lineament analysis is often performed to analyze surface and subsurface structural lineaments in terms of spatial (non-orientational) and orientational distributions.

In the orientational analysis, the azimuths of the lineaments were measured with respect to the geographical north. The measured orientations are further grouped in to angular intervals and rose diagrams are employed to display the orientations of the lineaments for further analysis.

3.4 Rose Diagrams

Rose diagrams are used to test the distribution of lineaments by direction (Hung *et al.*, 2013). Directional analyses of major and minor orientation of lineament trends are direction of the rose diagrams. The trend direction of the rose diagrams data are organized in class intervals of 15° . Each class represents the number of occurrences of event that fall within the specified angular region. A family of concentric circles provides scaled control for the number of fracture-orientation observations that occupy each class interval. The number of points from the selected data Column controlled the bar length within each class.

4.0 DISCUSSION

The colour shaded map of the total magnetic field intensity (TMI) values is presented in Figure 4 for the study area. Portions on the map that were shaded red represent areas of high magnetic intensity whereas those portions in blue correspond to areas of low magnetic field intensity. In-between these are intermediate colours of yellow and pale green representing areas of intermediate field intensities. The total magnetic intensity (TMI) anomaly map of the area is characterized by different size of wavelengths of anomalies; short wavelength (high wave number), medium wavelength (moderate wave number) and long wavelength (low wave number) anomalies. Generally, the amplitude of magnetic anomalies in the study area ranges from 32737.9 to 32929.8 nT and are predominantly aligned along NE-SW and E-W directions. The anomaly associated with the highest TMI value ranging from 32916.4 nT to 32929.8 nT is in the South-Western part and extending along the NE-SW direction up to the central part of the study area.

The second anomaly was observed in the northern half of the area extending from the NW part to NE part with high TMI values ranging from 32887.6 nT to 32911.8 nT. It is also obtained with short wavelength at the North-Eastern, South-Eastern, Western and Southern parts all trending either NE-SW or E-W direction. However, the anomalies with the lowest TMI values ranging from 32737.9 nT to 32824.4 nT were observed to be predominant at the northern half trending along NE-SW, ENE-WSW, E-W and NW-SE. The anomalies with the lowest TMI values are at the North-Eastern part with long wavelength, around the center with medium wavelength and at the South-Eastern part with the short wavelength.

The total magnetic intensity contour map is shown in Figure 5, which revealed the magnetic intensity values of different areas on the map. High magnetic intensity at the South-Eastern correlates with the basalts, Granite Gneiss complex and Magnetites which are associated with high magnetization. However, the low TMI values in the North-eastern correlates with Migmatite Gneiss which is characterized with high magnetization. This suggests that these basic rocks have lost substantial part of their magnetization either due to contact metamorphism and/or intense heat. Similarly, the North-western part of the map associated with high magnetization correlates with presence of the granites, basalts and migmatites in the area.

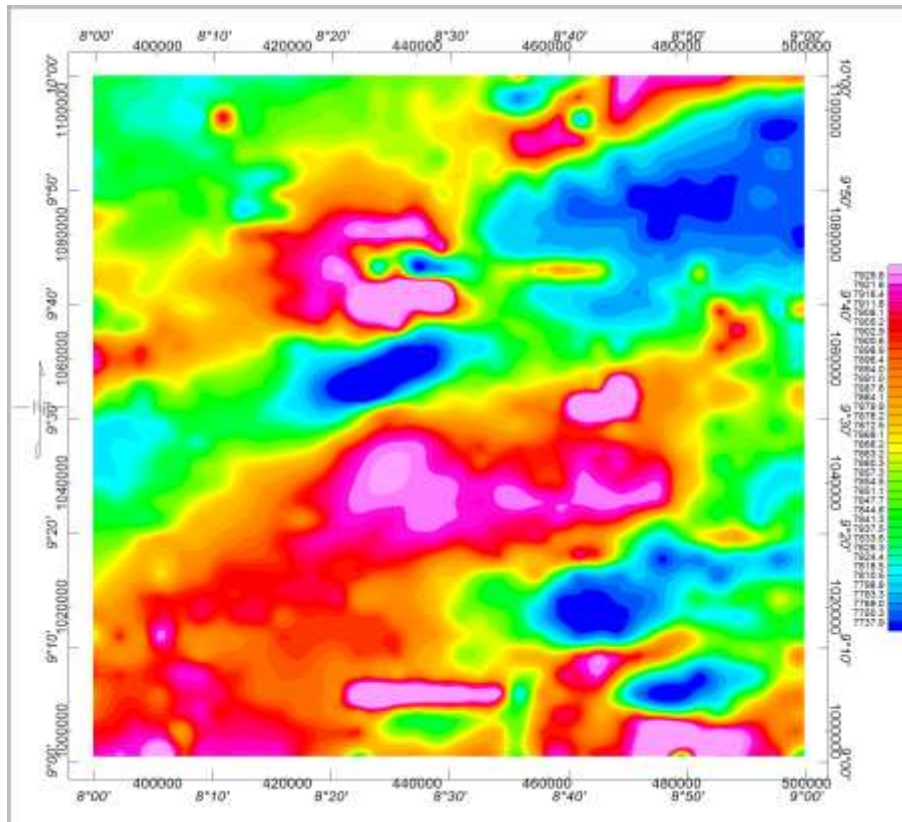


Figure 4. Total Magnetic Intensity (TMI) Map of the Study Area. To obtain the actual TMI values 25,000 nT were added.

First Vertical Derivatives

First Vertical Derivative (FVD) map enhances the anomalies. It shows the vertical rate of change in the Earth's total magnetic field. The edge of each anomaly appears clearer and most of the anomalies are in NE-SW direction which is the predominant trend of the northern Nigeria basement complex. Figure 6 shows the colour shaded FVD map of the study area. The blue colour indicates lower values while the pink colour represents higher values. Figure 6 also shows the lineament inferred after being digitized on screen to produce the structural map of the magnetic lineaments.

The lineament map, obtained from the FVD is shown in Figure 7a. The lineaments were inferred to be caused by faults and/or contacts due to their linear nature. As can be seen, the lineaments are widely spread out in the study area with the density of the lineaments being higher in the northern half than the southern half. However, the lineaments seem to be few in the upper part of the southern half of the study area.

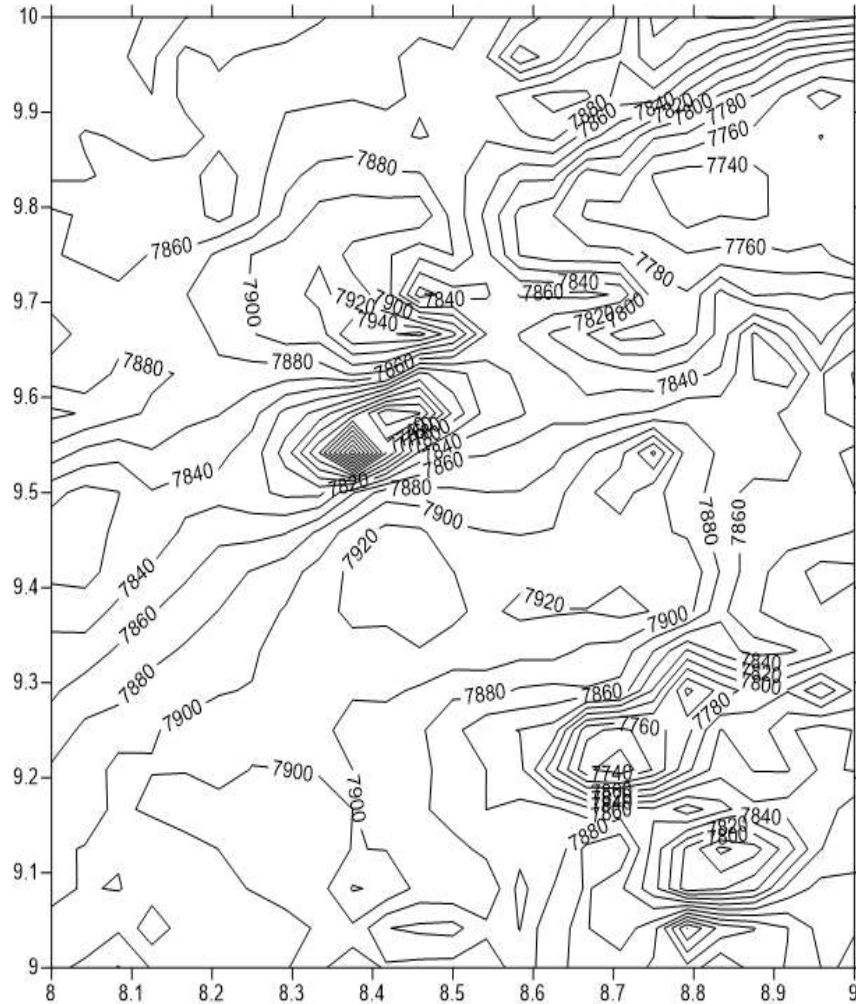


Figure 5. Total magnetic intensity contours map (Contour interval, 20 nT). To obtain the actual TMI values 25,000 nT were added to the contour values.

FVD (aeromagnetic) Lineament Analyses

To analyze the trends of the FVD (magnetic) lineament in the study area, the orientation of the lineament with respect to the geographical north were measured. The orientations were further grouped in to a class interval of 15° and the frequency of the lineaments in each class interval was counted, as shown in Table 1. Furthermore, a rose diagram of the structural trends in form of a polar plot, was plotted using Grapher (Version 8.0) software.

The frequency Table (Table 1) and the rose diagram (Figure 8) have shown that the trends of the structures are oriented along E-W, NE-SW, ENE-WSW, WNW-ESE, NW-SE and NNE-SSW in order of decreasing predominance. Among these trends, the trends inferred to be predominant (major) are in E-W, NE-SW, ENE-WSW and WNW-ESE directions. While NW-SE and NNE-SSW trends were inferred as minor trends.

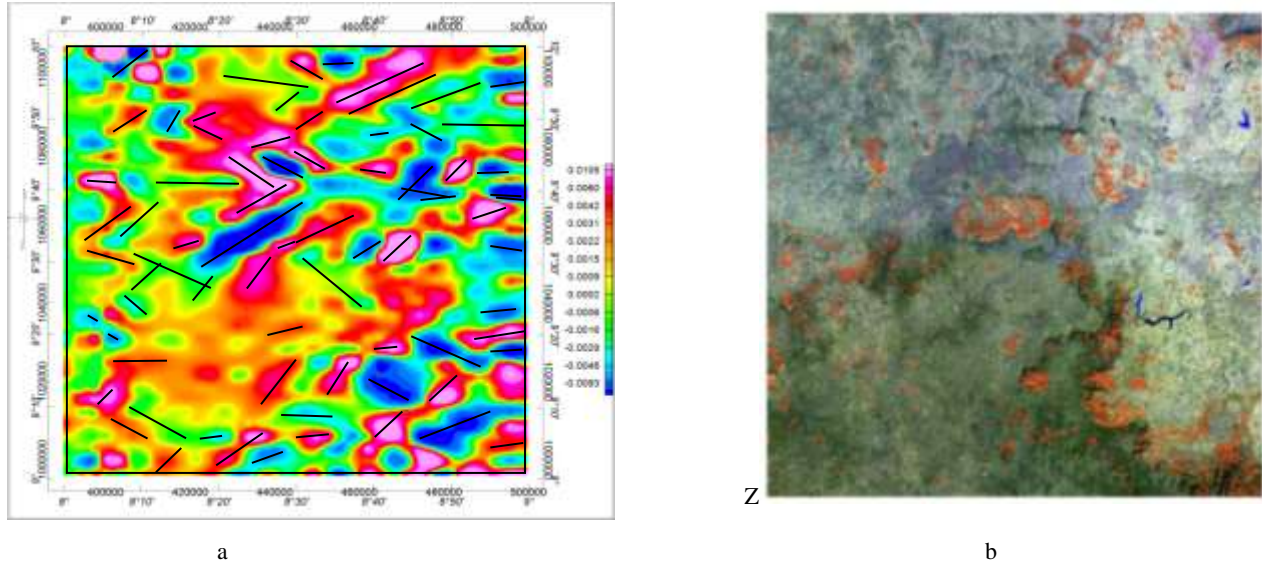
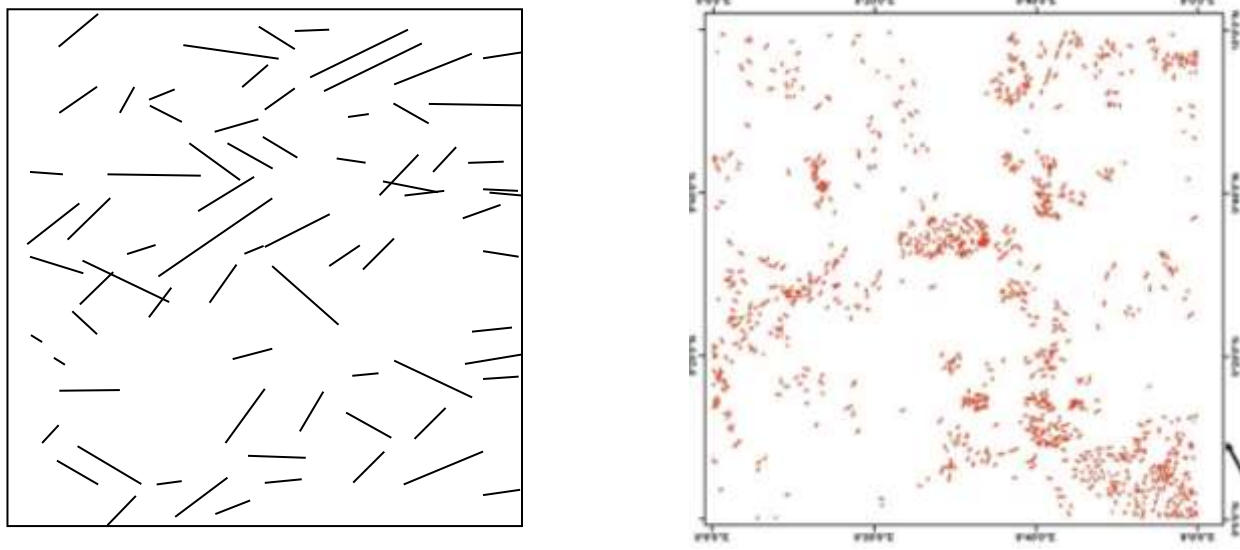


Figure 6.(a) First Vertical Derivatives Map Showing the Lineaments and (b) Landsat Lineaments Overlay on Satellite image of the Study Area



ab
Figure 7. Correlation of (a) Aeromagnetic Lineament Map and (b) Landsat Lineament Map

Table 1. FVD (Aeromagnetic) Lineaments Orientation Frequency Table

Class interval (degrees)	Frequency	Trends
1-15	0	N-S
16-30	2	NNE-SSW
31-45	12	NE-SW
46-60	10	NE-SW
61-75	12	ENE-WSW
76-90	15	E-W
91-105	6	E-W
106-120	10	WNW-ESE
121-135	5	NW-SE
	72	

Previous studies (e.g. Benedict, 1989; Akanbi and Mangset, 2011 and Raimiet *al.*, 2014) have shown the existence of E-W, NE-SW, N-S, NNW-SSE trending lineaments in other parts of the Nigerian younger granite province. Thus, the result obtained in this work correlated with the previous studies. Furthermore, the delineated ENE-WSW and the WNW-ESE trends obtained in this study perhaps reflect hitherto unmapped structural trends in the Nigeria younger granite province.

It is worth mentioning that the trends of the delineated structures correlate with the known structural trends in other parts of Nigeria. For example, the NE-SW and the ENE-WSW trends correlate with the general trend of the Benue trough (Ajakaiyeet *al.*, 1983), the NW-SE trend correlates with the trend of the Bida basin (Udensiet *al.*, 2003) and the WNW-ESE trends correlates with the Yola arm of the upper Benue trough (Anuduet *al.*, 2014).

The landsat lineament map was overlaid on the satellite image of the study area (Figure 6). And it was observed that the

major orientations of the Indsat lineaments coincide with the most of the known structural geological features.

Correlation of Aeromagnetic and Landsat Lineaments Maps

The delineated aeromagnetic (FVD) lineaments and inferred Landsat Lineaments maps have been correlated to infer possible structural control (Figure 7). This suggests that the predominant surface lineament were structurally controlled by the subsurface (aeromagnetic) lineaments. However, it was observed that the density of the surface lineaments is generally higher than the subsurface lineaments.

Further comparative analysis using rose diagrams (Figure 8), shows appreciable correlation between the NE-SW and NW-SE trends associated with the aeromagnetic and Landsat lineaments. This suggests that these trending Landsat lineaments contain appreciable amount of ferromagnetic minerals. However, the predominant NNE-SSW trending surface lineaments seem to be devoid of magnetic minerals.

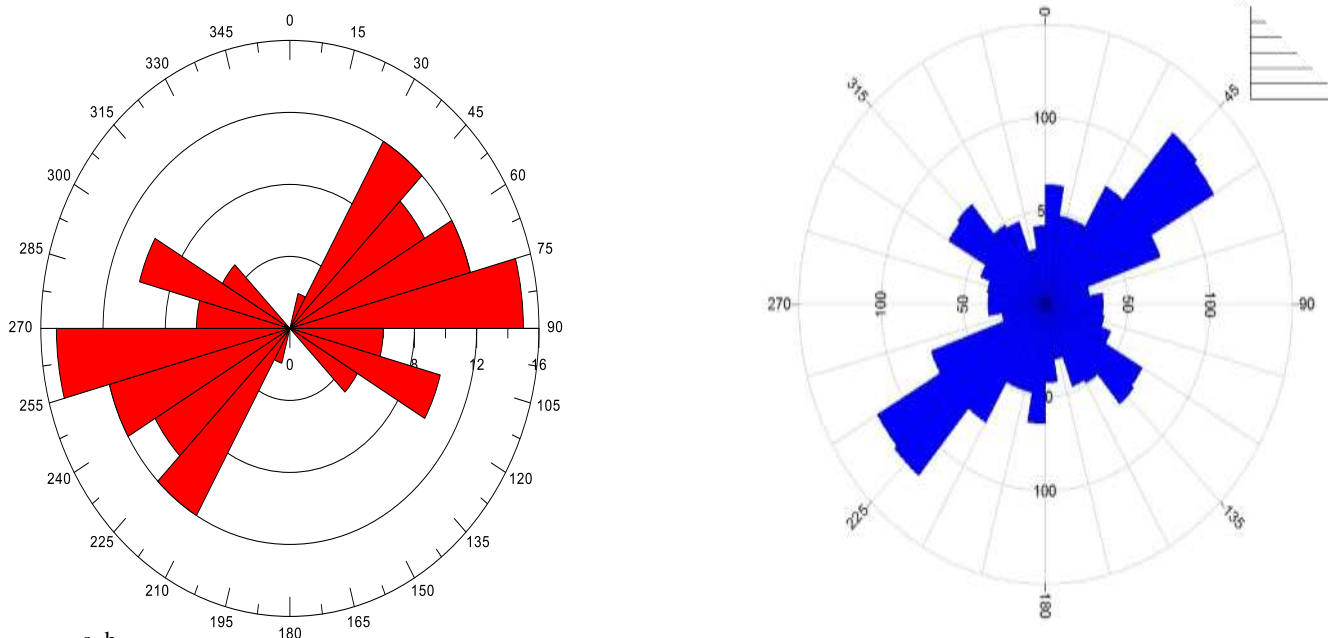


Figure 8. Correlations between (a) aeromagnetic Lineaments Rose Diagram and (b) Landsat Lineaments Rose Diagram

5.0 CONCLUSION

The TMI map produced by Oasis Montaj (Version 7.01) software was used to determine the trend of the anomalies. The anomalies are mainly in NE-SW and E-W direction with other anomalies in the ENE-WSW and NW-SE direction mostly with short wavelength. The trends in analysis of the magnetic field showed the high magnetic anomalies within the basement complex. The magnetic fields (both of total and residual) have dominant NE – SW with minor E –W directions which conform with the lineament trend directions within the Nigerian basement complex. The FVD map was used to infer lineaments trend. The lineaments are trending in NE-SW and

ENE-WSW directions as the major orientations with minor ones in NNE-SSW and E-W. Lineament analysis using rose diagrams was carried which indicates possible structural control of surface (Landsat) lineaments by the FVD (aeromagnetic) lineaments. The TMI showed the presence of near surface igneous intrusive within the basement complex. This include the high magnetization contrast in the NE and SE parts of the study area which correlates with the migmatite-gneiss, biotite-granites, granites and basalts which are associated with high magnetic contrasts. Also, the high magnetization contrast in the NW part of the area correlates with basalt and the biotite-granite. These areas of high

magnetization are the mineralization zones where the mentioned magnetic minerals are highly expected.

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