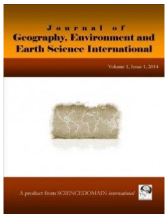

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# Qualitative Interpretation of Recently Acquired Aeromagnetic Data of Naraguta Area, North Central Nigeria

**E. J. Ngama[1*] and E. S. Akanbi[1]**

[1]*Department of Physics, University of Jos, Nigeria.*

***Authors' contributions***

*This work was carried out in collaboration between both authors. Authors EJN and ESA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors EJN and ESA managed the analyses of the study. Author EJN managed the literature searches. Both authors read and approved the final manuscript.*

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## ABSTRACT

This study on Qualitative Interpretation of recently acquired aeromagnetic data of Naraguta, sheet 168 was aimed at analysing and interpreting the data, identifying the subsurface structures and the mineralized zones. Using some software packages, the data was analysed using the following processes; Total Magnetic Intensity (TMI), Reduced-To-Equator (RTE), Upward Continuation and First Vertical Derivative (FVD). Results from the analysis show that the magnetic intensity range for TMI map varies from -696.9 to 599.2 nT/m, RTE varies from -430.1 to 346.4 nT/m both showing anomalies in circular to near circular closures which could be associated with granitic intrusions, long narrow features which could be dykes or long ore bodies and dislocations which could be due to subsurface fractures. Upward continuation map at 3 km deep revealed a basement trending mostly in the NE-SW and ENE-WSW directions with the latter being the major trend direction. The first vertical derivative sharpened the anomaly edges which were extracted to produce the lineament map and to obtain the rose plot. The rose plot shows the dominant lineament trend to be in the NE-SW direction. Finally, the analytic signal maxima may represent the edges of circular, elliptical or polygonal porphyritic ring dykes that characterize many of the complexes in the study

**Corresponding author: E-mail: ngamaebuka@gmail.com;*

area. Comparison of this study with previous research done using an old data of Naraguta sheet 168, shows similarities with few differences noticed especially in the TMI map which may be attributed to sophistication in equipment used or the effects of temporal variation on the geomagnetic field of the earth which helped in making visible anomalies that were hidden in the former data of Naraguta sheet 168.

*Keywords: Aeromagnetic data; Naraguta sheet 168; TMI map; trend; rose plot.*

## 1. INTRODUCTION

The earth is divided into three major parts; core (inner core, outer core), mantle (upper and lower mantle) and crust. The inner core is the solid part made up of iron and is surrounded by the outer core which is nearly 2000 km thick and is composed of iron, nickel and small quantities of other metals. Differences in pressure, temperature and composition within the outer core causes convection current which leads to flow of liquid iron which generates currents which in turn produces magnetic fields (Earth's Magnetic field). These convection processes in the liquid part of the core (outer core) give rise to a dipolar geomagnetic field that resembles that of a large bar magnet aligned approximately along the earth's rotational axis. The mantle plays little part in the earth's magnetism, while interactions of the past and present geomagnetic field with the rock of the crust produces magnetic anomalies recorded in detail when surveys are carried out. The use of magnetic methods for survey was one of the earliest geophysical survey tool used by mankind in investigating subsurface geology on the basis of the anomalies in the earth's magnetic field resulting from the magnetic properties of the underlying rocks, though there is this lack of uniqueness obtained from result interpreted. The survey is cheap, reliable and requires little or no corrections on the observations. The study was motivated by the fact that previous interpretation of Aeromagnetic data of Naraguta, sheet 168, was done using data obtained between the years 1975 to 1978, so there is the need to interpret the recent data obtained between the years 2003 to 2009. This research will be of great benefit to individuals, companies and the government as there is the likelihood of identifying new structures and supporting existing structures when compared with previous research carried out in the area. This will help in identifying subsurface structures as well as mineralised zones in the region.

### 1.1 Study Area

The study area is located in the North Central Nigeria (Fig. 1), bounded by longitude 8°30' E - 9°00' E and latitude 9°30' N -10°00' N covering an area of about 2970.25 sqkm and comprising of the following towns: Jos, Bukuru, Vom, Barkin Ladi, Rukuba, Foron, Miango, Kigom, Ganawuri etc. The study area has high relief features with elevation range between 1800 m to 5300 m above sea level. The Jos-Plateau owes its preservation largely to the close concentration of resistant Younger Granites and Older Granites, and indeed almost all the upland areas coincide with outcrops of one of these two rocks [1]. The Jos-Plateau is dominated by three rock types (Fig. 2): Basement Rocks, Younger Granite Rocks and Basalts or Basaltic Rocks. The study area is an area of Younger Granite Complexes, forming distinctive groups of intrusive and volcanic rocks bounded by ring dykes or faults [1]. Volcanic activities which occurred several years ago, created vast basaltic plateau and volcanoes, producing regions of mainly narrow and deep valleys, and sediments from the middle of rounded hills with shear facies. Other rocks found in the area are Basic rocks (Gabbro and Dolerite) and Basement rock such as Migmatite which are resistant to erosion.

The Younger Granites are emplacements dating to the Jurassic, around 160 to 170 million years and forming part of a series that includes the Air Massif in Central Sahara. There are also many volcanoes and sheets of basalt extruded since the Pliocene. The Younger Granites contain tin, which was mined since the beginning of the 20th century [2].

The Older Granites and the accompanying metamorphism of the basement are dated to the late Cambrian and Ordovician about 500 to 600 million years, and represent the Pan African Orogeny in Nigeria [3]. However, it seem likely that emplacement of the Younger Granites was associated with Epeirogeric uplift [4]. Indirect evidence for this is lack of sediments associated with the volcanic rocks of the Younger Granites age, which are apparently erupted on to land surface undergoing erosion, not deposition [4].

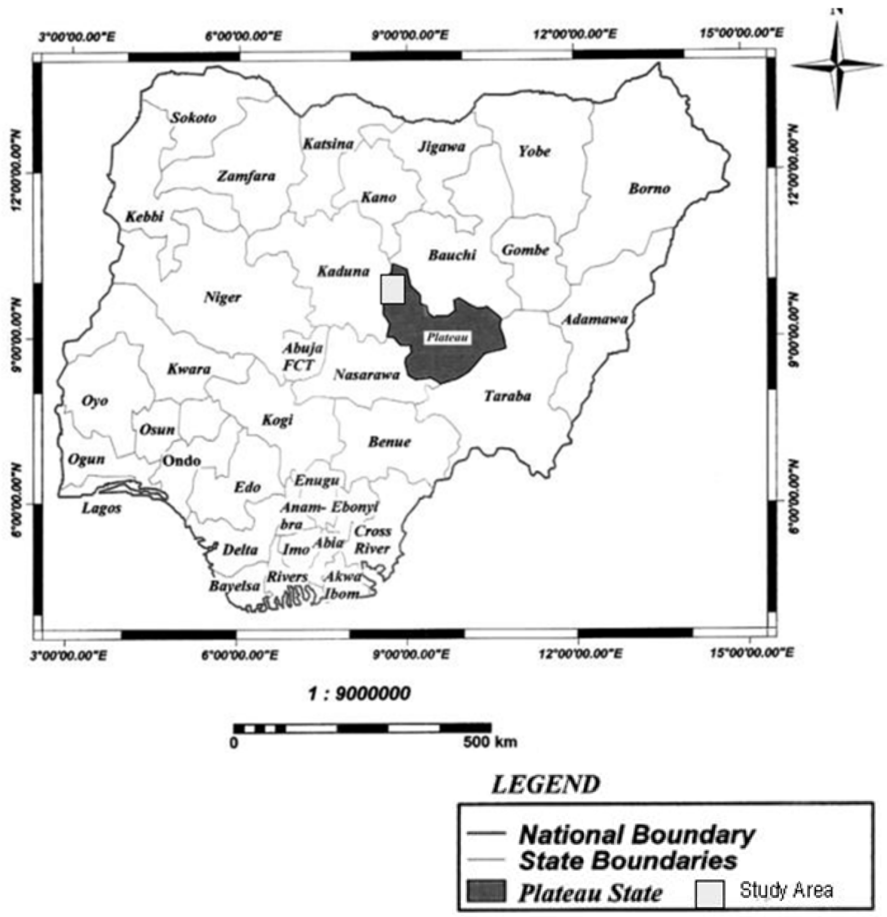


**Fig. 1. Map of Nigeria showing study area**

## 1.2 Data Acquisition

The data was obtained using a high resolution geophysical survey involving magnetic, radiometric and limited electromagnetic survey carried out between the years 2003 to 2009. The programme began with a pilot scheme in Ogun state, Nigeria and later divided into phases (1 and 11) to cover other parts of the country. The survey was carried out by the Nigerian Geographic Survey Agency (NGSA) in conjunction with Fugro Airborne Survey Ltd with the objective of accelerating mining sector investment in the country. The survey was carried out with the magnetometer fixed to the wing of an aircraft. Naraguta sheet 168 was part of Block C covering a total of 246, 000 line kilometers and obtained at a flight spacing of 200 meters and terrain clearance of 80 meters. The flight direction was in the NW-SE with line spacing of 2000 meters and tie line direction of NE-SW.

## 1.3 Interpretation of Magnetic Data

As with all geophysical interpretation, the analysis of magnetic data has two distinct aspects: qualitative and quantitative. The qualitative process is largely map-based and dominates the early stages of a study. The resultant preliminary structural element map is the cornerstone of the interpretation. Certain qualitative conclusions are readily drawn from a magnetic map. Anomalous conditions in the sub surface are indicated, for instance by successive closed contours with the anomaly value increasing or decreasing towards a centre, while the direction of the elongation of the closed curves may be identified with the length direction (the strike) of the anomalous body. However, a caution is in place in this respect because in low magnetic latitudes bodies of finite length, striking north-south, produce anomaly patterns which indicate an east-west strike [5]. Another indication is given by high horizontal anomaly gradients. They are often associated with rocks of different susceptibilities or unequal total intensities of magnetisation, the contact lying lower the steeper gradient. A considerable amount of qualitative interpretation of magnetic maps consists of recognizing and delineating anomaly patterns [5]. The interpretations of various anomaly patterns on a magnetic map in terms of rocks must be made in conjunction with available field geological observations. Conversely, availability of a magnetic map is of the greatest use in constructing the geology in areas with sparse rock outcrops [5].

The quantitative phase begins with the process of putting lines during the qualitative phase. Refinement of these locations begins with the determination of depth values. For example, depth estimates to tops of anomalous magnetic bodies are generated by a number of means including: slope measurement methods, analytic methods such as Euler and Werner deconvolutions.

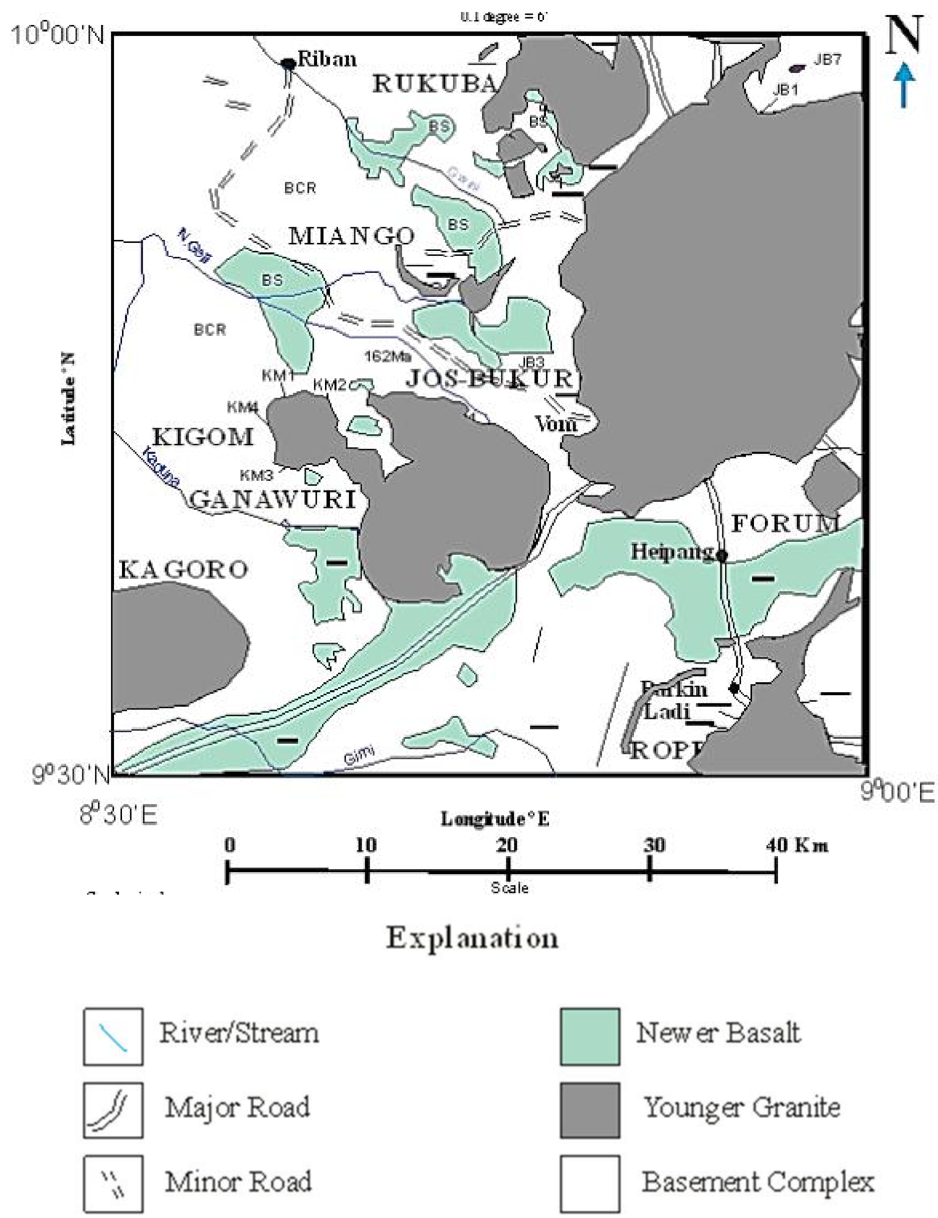


**Fig. 2. Geology map of study area modified [6]**

## 2. MATERIALS AND METHODS

The data sets used for this research are;

1. Soft copy of Aeromagnetic data covering Naraguta area sheet 168 (1: 100 000) [7].
2. Soft copy of Nigeria Geological survey map covering Naraguta sheet 168 (1: 100 000) [8].
3. Soft copy of topography map of Naraguta area sheet 168 (1: 100 000) [9].

The software packages include;

1. Oasis Montaj from Geosoft world version 6.4.2
2. ArcGIS

The following steps were taken;

1. The Total Magnetic Intensity (TMI) map was obtained by geo-referencing the airborne data using the Oasis Montaj software.
2. To obtain the Reduced-to-Equator (RTE) map, the TMI data was filtered in accordance with the I.G.R.F reduction technique. The RTE filter makes the magnetic anomalies to be symmetrically centered over their corresponding sources and also corrects for the effect of latitude.
3. The Upward Continuation (UC) map was obtained by applying the UC filter to the TMI map. UC filter smoothens data i.e. reduce the high frequencies (including noise). It has ability to reduce scattered measurements into a common level for simpler interpretation.
4. The First Vertical Derivative (FVD) filter was applied to the RTE data to enhance anomalies made hidden by broader regional trends. This it does by suppressing unwanted sources and enhance some or sharpen the edges of the anomalies.
5. Using lineaments marked out in the FVD map, the lineament map was obtained. This was further used to obtain the Rose Diagram plot using the ArcGIS software.
6. The Analytical Signal map was also obtained using the Oasis Montaj software. The analytic signal filter produces a particular type of calculated magnetic anomaly enhanced map used in defining edges (boundaries) of geological anomalous magnetisation distribution in maps.

## 3. RESULTS PRESENTATION AND INTERPRETATION

### 3.1 Total Magnetic Intensity (TMI) Map

The TMI map shows the variation in magnetic intensity indicating variations in either lithology or basement topography. The map (Fig. 3) obtained has a magnetic intensity range of between -695.9 nT/m to 599.2 nT/m. Anomalous conditions in the sub surface are indicated by successive closed contours represented by high and low in Fig. 3. Circular to near circular closures were observed around the central region which could be associated with granitic intrusions; long narrow features which are frequently due to dykes, long ore bodies can be seen at the NW and NE section of the map and dislocations shown using black ticks trending mostly in the NE-SW and NW-SE directions. These observations are in agreement with past researches, for example the one done by Akanbi and Mangset [10] (Fig. 4a) using the old data except for the linear anomaly located in the NW part which is not observed in their study. Also, in work done by Opara et al. [11] as shown in Fig. 4b, the long narrow features were not visible but the magnetic intensity distribution over the region are similar with that obtained using the recent data as shown in Fig. 3.

### 3.2 Reduced-to-Equator (RTE) Map

The RTE map in Fig. 5 shows a map corrected for latitude with the anomalies symmetrically located over their sources. The RTE filter was applied in accordance with International Geomagnetic Reference Field (I.G.R.F) reduction technique, using a geomagnetic inclination angle of -4.03517° and geomagnetic declination of -1.34213°. High and low magnetic intensity values could be observed all over the map with an intensity range of between -430.1 nT/m to 346 nT/m. The intensity values observed could be attributed to the rock types present in the region and the mineral composition of this various rocks. Jos-Bukuru, Rukuba and Ropp complexes are regions with low magnetic intensity anomalies. These are mostly Younger Granite complexes composed of biotite granitic rocks with felsic intrusive igneous rocks containing quartz, silicate minerals and feldspar which are formed within the earth's crust from the crystallisation of magma and appear as plutonic rocks.

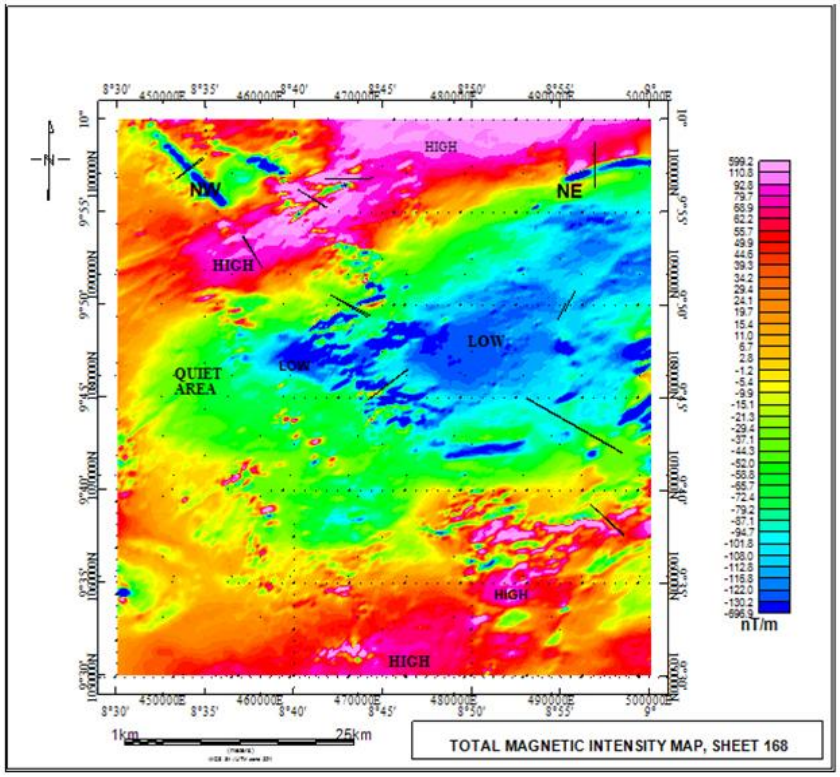


**Fig. 3. Total magnetic intensity map of Naraguta, sheet 168 (lines represent dislocations)**

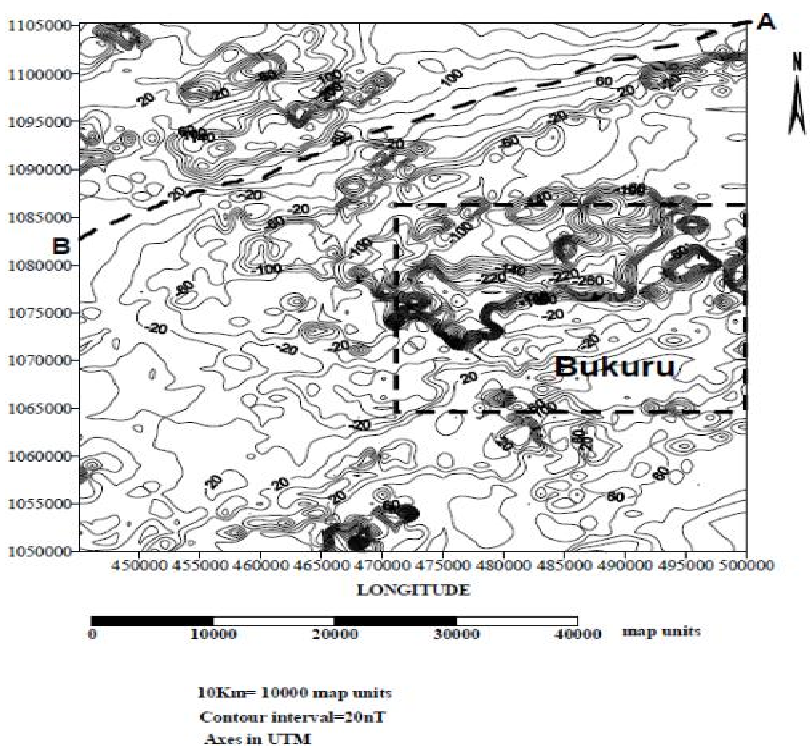


**Fig. 4a. Airborne magnetic residual map of study area [10]**

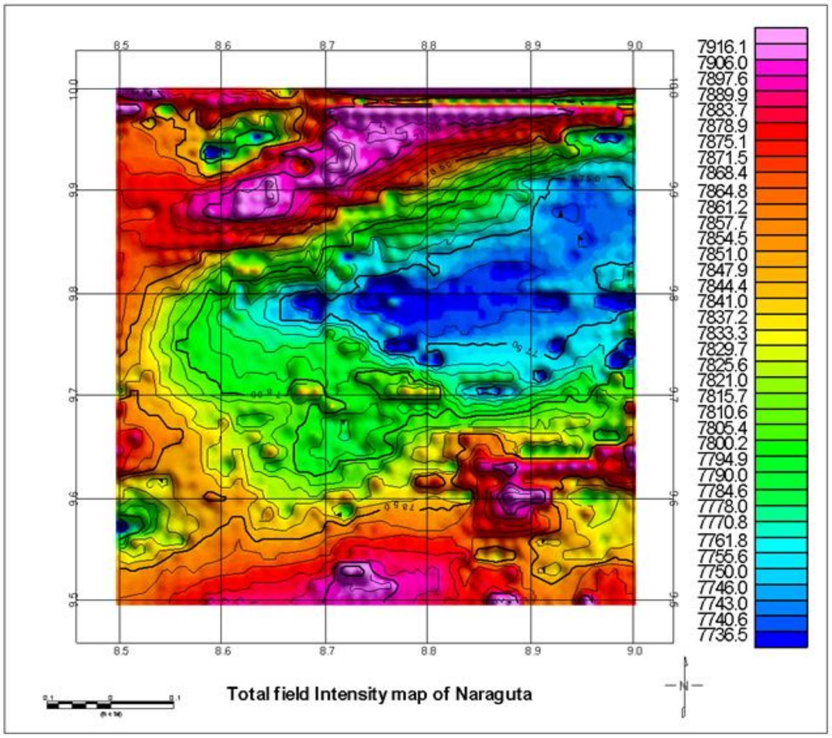


**Fig. 4b. Total magnetic intensity map of Naraguta, sheet 168 [11]**

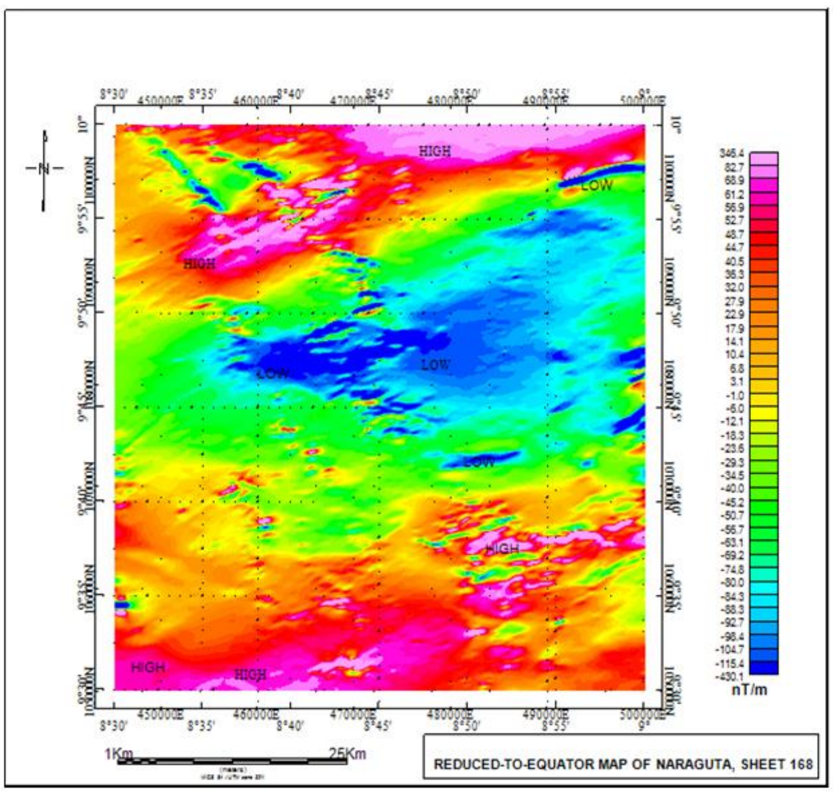


**Fig. 5. Reduced-to-equator map of Naraguta, sheet 168**

Areas around Miango, Ganawuri-Kigom are regions with high magnetic intensity value. These areas are composed of rocks with high iron content such as migmatite and riekbeckite.

### 3.3 Upward Continuation (UC) Map

Upward continuation filter was used in suppressing the effect of narrow anomalies in other to obtain information on deeper anomalies. The TMI map was upward continued for 1 km, 2 km and 3 km. At 3 km, the regional anomalies became more visible, showing clearer view of the regional basement trend and anomalies. The map as shown in Fig. 6 has an intensity range of between -92.9 nT/m to 80.1 nT/m with the far northern and southern end comprising of parts of Rukuba and Ropp having a positive intensity anomaly (pink). These are basement complexes underlain by rocks such as migmatite. Negative intensity anomaly (blue) range of between -92.9 nT/m to -54.1 nT/m was observed around the central part which is in a circular form comprising mainly of rocks underlying the Jos-Bukuru complex. The regional anomaly is indicative of the deep features and is observed trending mostly in the NE-SW and ENE-WSW directions with the latter being the major trend direction. This direction agrees with the regional trend observed by Akanbi et al. [12] on applying second order 2-D least square polynomial fitting method on aeromagnetic data obtained between the years 1975-1978. In the work, the trend was in the ENE-WSW direction as shown in Fig. 7.

### 3.4 First Vertical Derivative (FVD)

The first vertical derivative filter sharpens the edges of anomalies which aid in locating their positions. The FVD map in Fig. 8 has a magnetic intensity range of between -0.615 nT/m to 0.803 nT/m. H1, H2, H3 and H4 are indications showing regions with magnetic highs which are basically fresh basement outcrops. Older weathered outcrops are shown as regions with a mixture of highs and lows comprising of areas around Foron, Ropp and parts of Ganawuri-Kigom complexes. Generally, these regions are underlain by Precambrian and/or lower Palaeozoic Basement Rocks where Younger Granites intrude into the Older Basement Rocks.

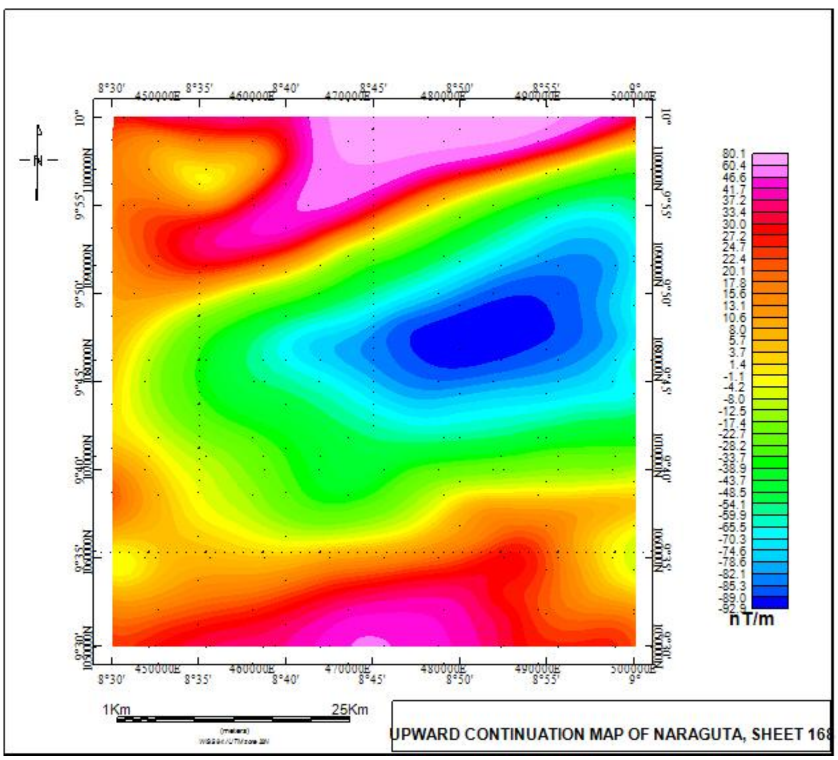


**Fig. 6. Upward continuation map of Naraguta sheet 168, at 3 km**

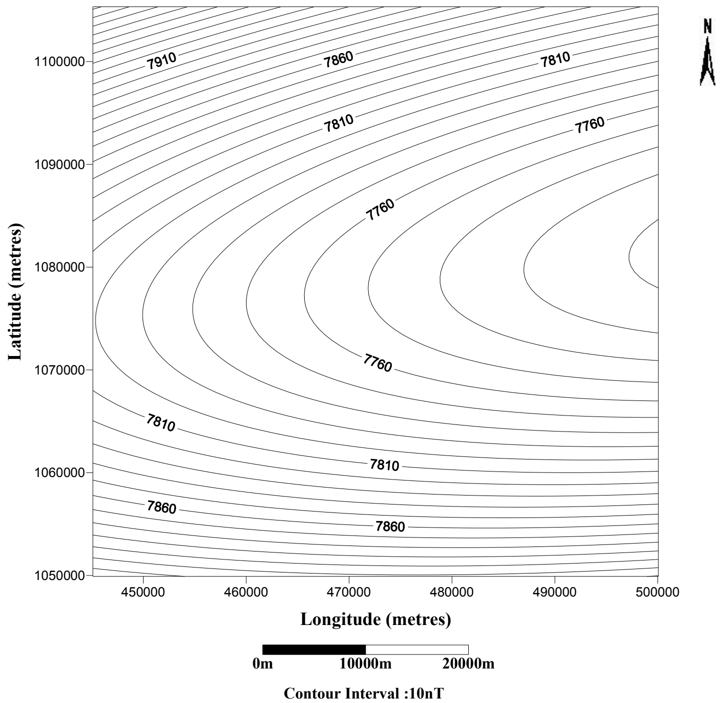


**Fig. 7. Regional magnetic intensity map of Naraguta area, sheet 168 using data obtained between 1975-78 survey [12]**

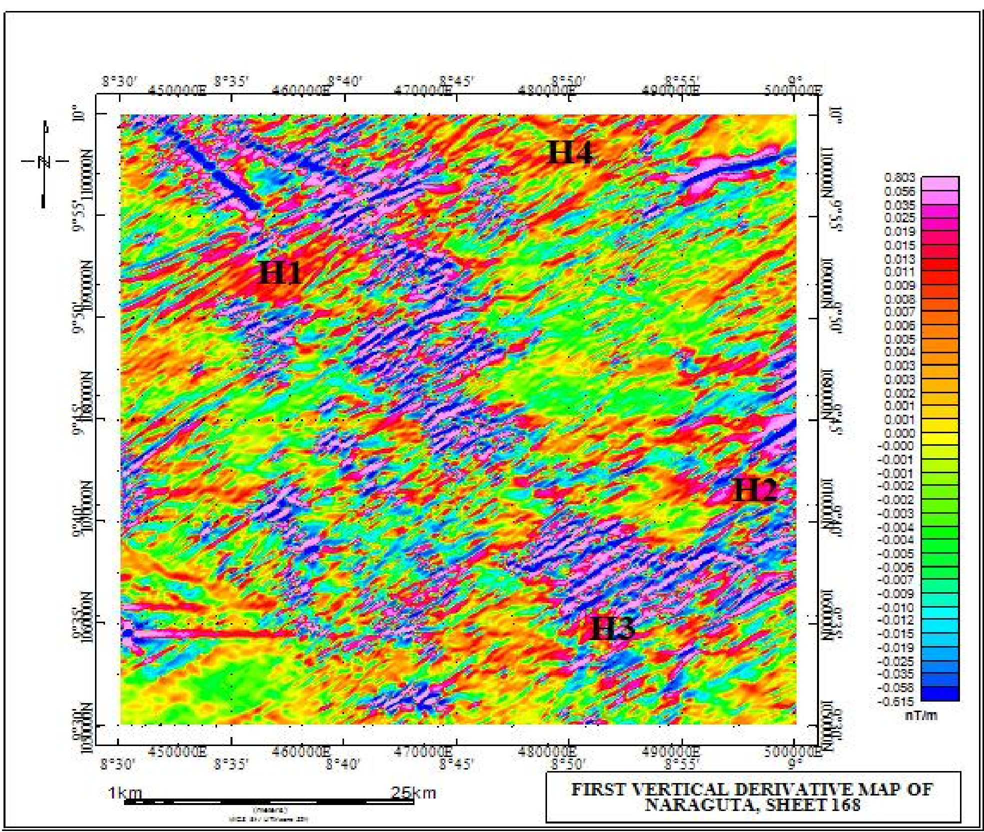


**Fig. 8. First vertical derivative map of Naraguta, sheet 168**

### 3.5 Lineament Arch and Rose Diagram

Lineaments are features in a landscape which is an expression of the underlying geological structures such as fault, fracture zones, shear zones and igneous intrusions such as dykes. The lineament observed as shown in Fig. 9 when compared with the geology map of Naraguta sheet 168, could be said to be basic dykes, aplite dykes, felsite dykes, pegmatite dykes and quartz vein. The different dykes mentioned earlier have different method of formation and are host to minerals such as plagioclase and alkali feldspar, quartz, micas, zircon, magnetite and tourmaline. The lineament direction is mostly in NE- SW and NW-SE direction with a few lineaments observed in the Jos- Bukuru complex. This could be because in the Younger Granite province local lineaments discernable are mostly fracture lines defined by joints that are formed as a result of tensional stresses. These form a network cross cutting each other, which generally decrease in width and size with increase in depth, as they are commonly sealed up at depth by the lithostatic pressure and/or siliceous materials. Because geologic features are often large, structural analyses are conducted on regional scales, to provide a comprehensive look at the extent of faults and other structural features [13]. Hence lineaments that are joints may not be discernable on regional scale as the magnetic survey was conducted on a regional scale. Comparing the lineaments extracted from the aeromagnetic map of this study with the lineaments extracted from Landsat ETM+ imagery (Fig. 10) covering the same area produced in 2002 [14], it is observed that local lineaments are not visible but the regional features of length ranging from about 150 m to 17500 m are visible. This does not imply that smaller lineaments of anorgenic origin do not exist but these are more visible during ground trothing [14]. According to Akanbi, [14] although these lineaments have different orientations, two predominant trends are more visible, a major (NE-SW) trend and a minor (NW-SE) trend.

Similarly, the rose diagram plot in Fig. 11 shows the lineament to major in the NE-SW and NW-SE trend. This is in agreement with the trend direction NE-SW and NW-SE obtained by Opara et al. [15] as shown in Fig. 12a and in that obtained by Akanbi [14] extracted from Raw Landsat ETM+ Imagery in 2002 as shown in Fig. 12b. Generally, many individual lineament trend correlate favourably with the NE-SW and NW-SE trending anomalies dominant on the lineament map and rose plot produced in this study.

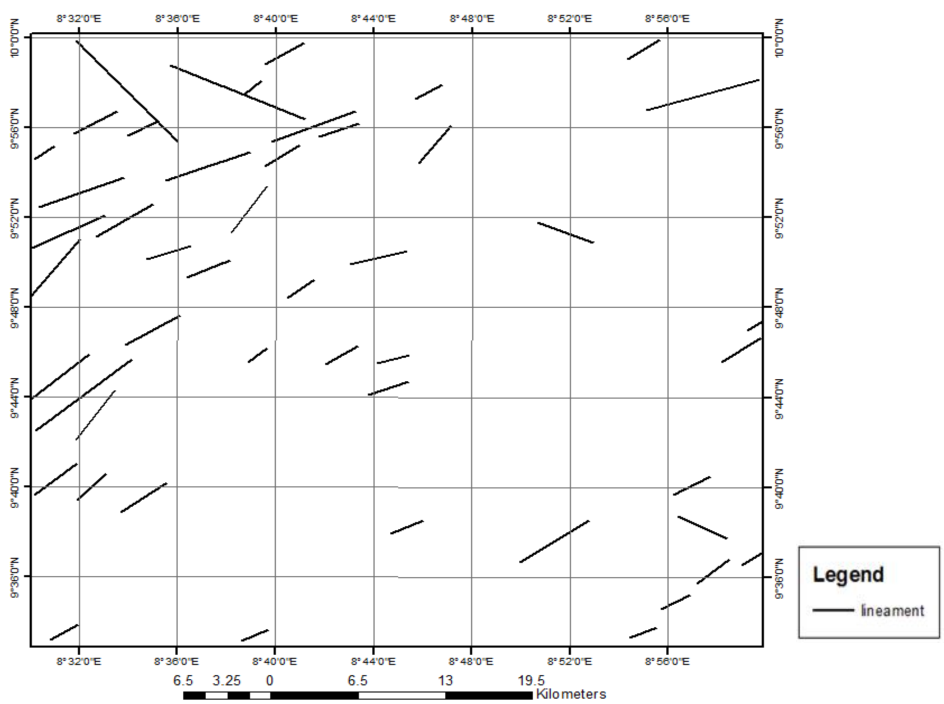


**Fig. 9. Lineament Archs extracted from FVD map of Naraguta sheet 168**

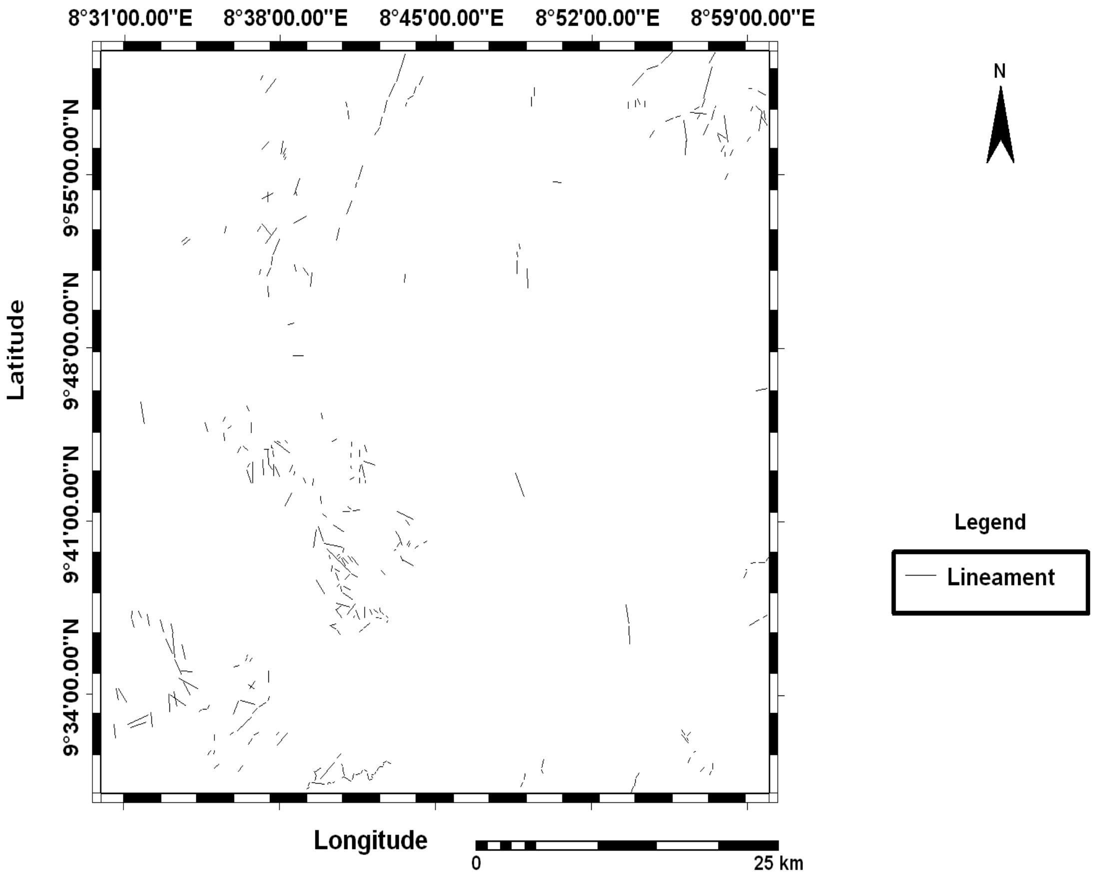


**Fig. 10. Digitised Lineament Map of Naraguta Area, Sheet 168 (As extracted from Raw Landsat -7 ETM+ Imagery (2002) [14]**

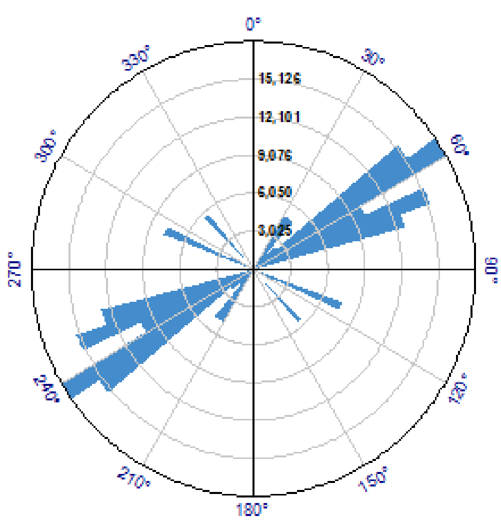


**Fig. 11. Rose diagram from lineaments. (With distance in Kilometres)**

### 3.6 Analytical Signal

Analytic signal map shows the variation in the magnetisation of the magnetic sources in the study area. All bodies with the same geometry have the same analytical signal. Mapped maxima (ridges and peaks) in the calculated analytic signal of a magnetic anomaly map locate the anomalous body edges and corners. The strength of the magnetisation of the underlying rocks is related to the amplitude of the analytic signal. In this study, black ticks were used to show the maxima on the map as shown in Fig. 13. The map has an amplitude range of between 0.000 nT/m to 3.555 nT/m. High peaks was observed in parts of Ropp, Heipang, Miango and Rukuba complex. In this study the analytical signal maxima may represent the edges of circular, elliptical or polygonal porphyritic ring dykes that characterize many of the complexes in the study area.

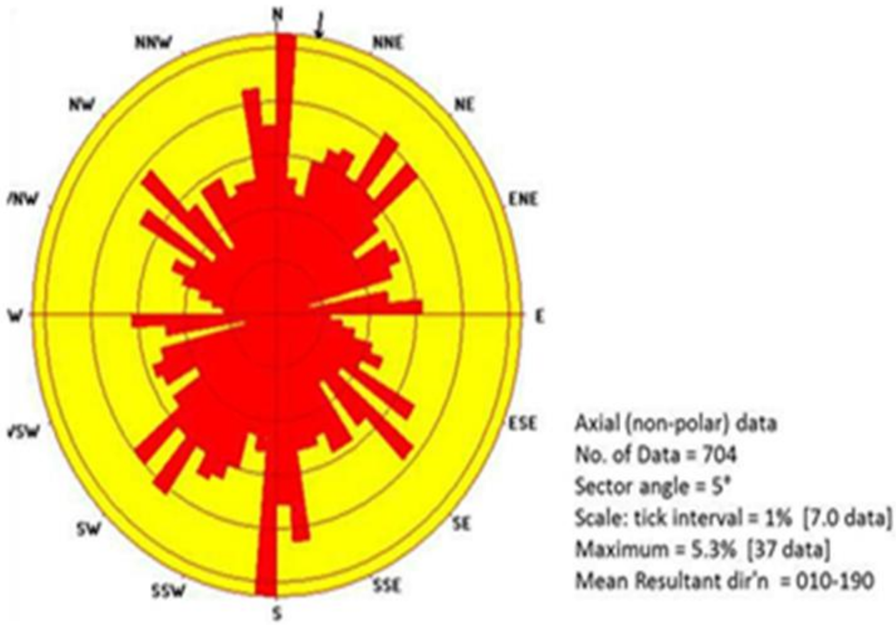


**Fig. 12a. Rose plot generated from lineaments of study area [15]**

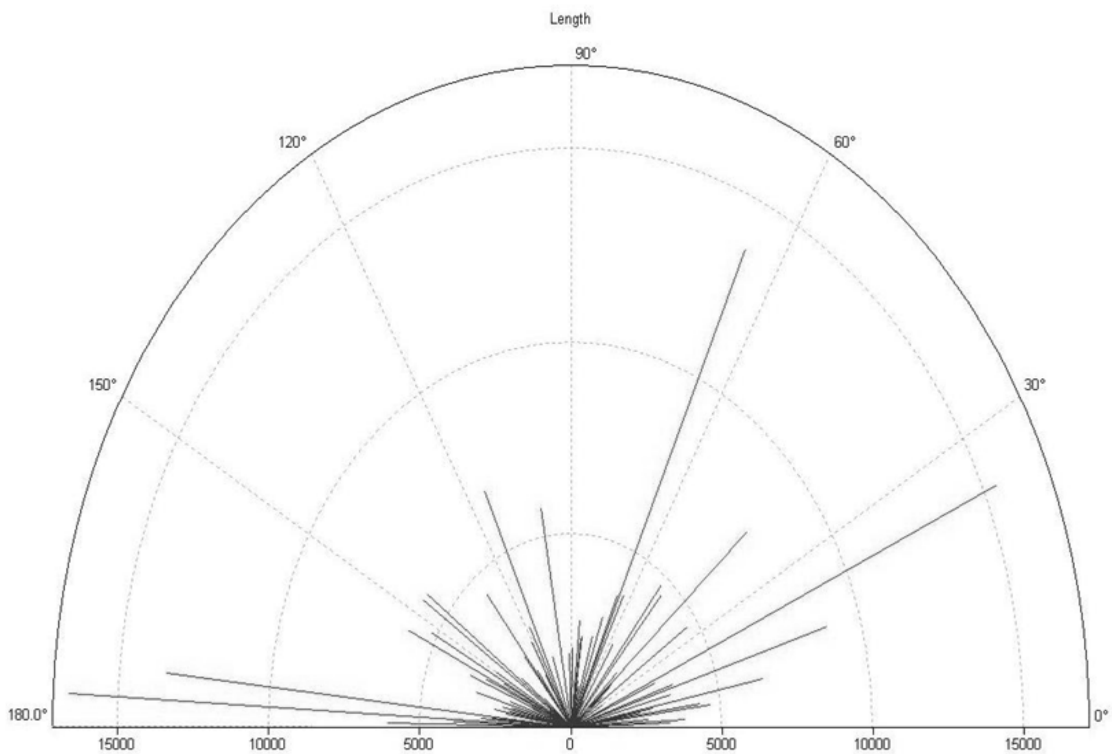


**Fig. 12b. Rose plot showing Lineament trend of Naraguta area, sheet 168, extracted from Raw Landsat -7 ETM+ Imagery (2002). The dominant trends are NE-SW and NW- SE trend. [14]**

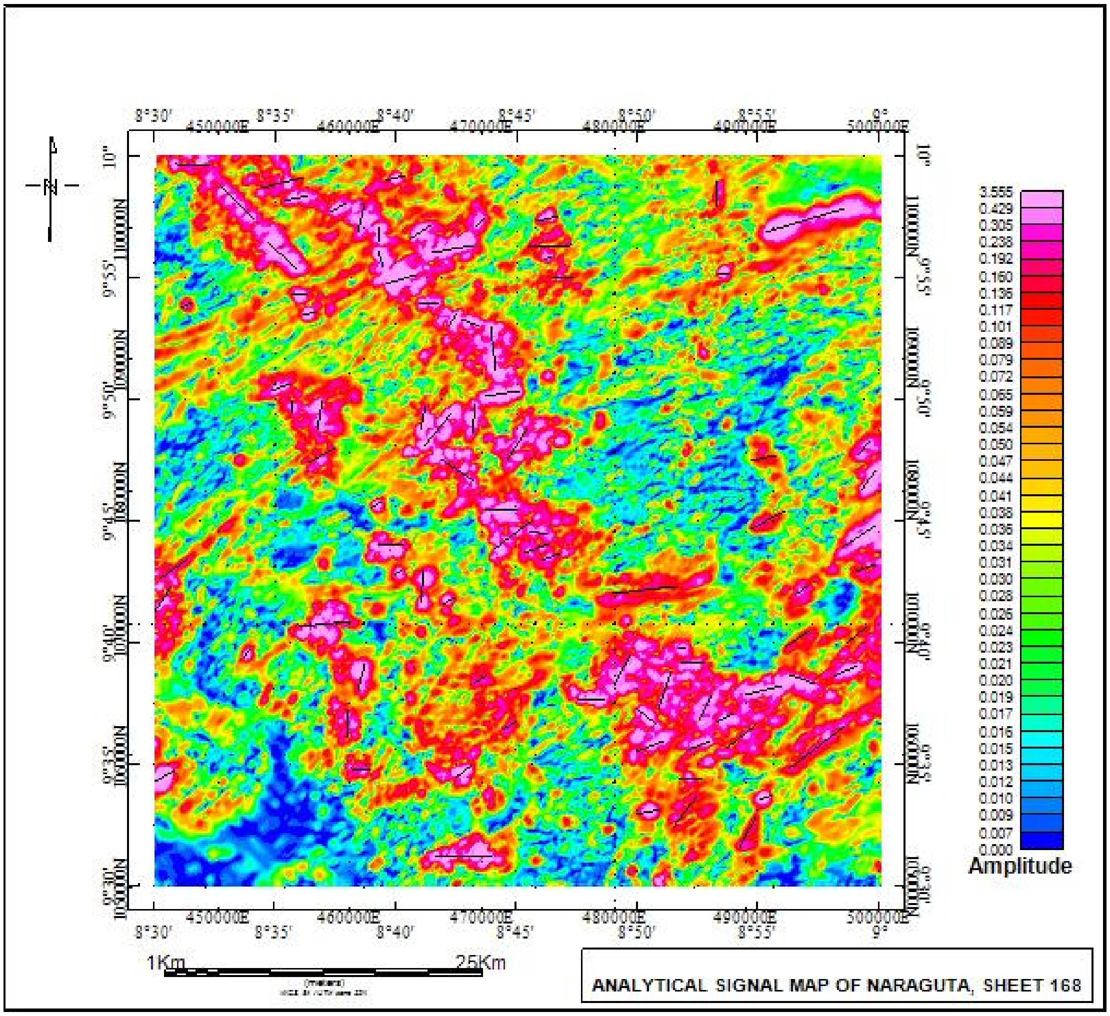


**Fig. 13. Analytical signal map of Naraguta, sheet 168**

## 4. CONCLUSION

The data set was analysed using different filters to enhance geological features within the study area. A few changes were observed between work done on this recent data set obtained between the years of 2003 to 2009 when compared with work done on the former data obtained between the years of 1975 to 1978. These changes could be attributed to the temporal variation in the geomagnetic field which tends to affect magnetic anomaly direction and position. Also, use of better technology for survey and sophisticated software packages for analysis can be responsible for the changes observed. Analysis carried out using the TMI, RTE and UC filters were helpful in identifying different magnetic anomalies within the study area, while the TMI and RTE map shows the variations in both the magnetic intensity and the basement topography in the area, the UC map shows delineated deep structures in the region. FVD filter was useful in marking out the lineaments and subsequently aided plotting of the Rose Diagram which shows the anomaly trend directions. Anomalies observed from the maps are in the form of circular features, long narrow features and dislocations which are all associated with granitic intrusions or ore bodies, dykes and long ore bodies. Circular features were observed around the Jos-Bukuru and Kagoro Complex. Based on the presence of linear structures and granitic intrusions, the region has great prospects for mineral exploration. The Jos-Bukuru Complex from this study is a low magnetic intensity region. The region is a Younger Granite Complex composed of biotite-granite rocks which occur in association with cassiterite which is an ore for tin and columbite.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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