# DELINEATION OF MINERAL POTENTIAL ZONES OVER LOWER PART OF SOKOTO BASIN, NORTHWESTERN NIGERIA USING AEROMAGNETIC DATA

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## ABSTRACT

*In an attempt to delineate mineral potential zones, Subsurface investigation was carried out over the lower part of Sokoto basin northwestern Nigeria. The area lies between latitude 10.5$^o$N to 11.5$^o$N and longitude 04$^o$E to 05$^o$E with an estimated total area of 12,100km$^2$. Four (4) high resolution aeromagnetic data sheets were acquired from the Nigerian Geological Survey Agency (NGSA) and were processed in to total magnetic intensity (TMI) map using Oasis Montaj. The result was interpreted using qualitative approach. The composite total magnetic intensity (CTMI) map revealed heterogeneity in the magnetic signature, ranging from -64.1nT to 123.6nT. Regional-residual separation was performed on the composite total magnetic intensity map using polynomial fitting. The residual map was subjected to first and second vertical derivatives, downward continuation, analytic signal and tilt derivative. The result of the analyses, gave rise to some directional gradient maps consistently depicting NE-SW trending lineaments. The result was further authenticated by comparing the first vertical derivative map with the lineament map of the study area which revealed some degree of agreement. Hence, the lineaments and veins identified could play host to mineralization in the area.*

**Keywords:** Aeromagnetic, Derivatives, Analytical Signal, Tilt derivative, Lineaments and mineral

## 1. INTRODUCTION

Minerals are naturally occurring substances that have characteristic chemical composition and in general, a crystalline structure (Oxford Science Dictionary, 2010) [1]. Solid minerals are natural resources that form part of the Earth resources which beckon human race for exploitation, extraction and utilization. The country's history in mining has reinforced the incontrovertible fact that it is very well endowed with a large variety of solid mineral located in the upper few kilometers of the earth (crust). It is in this outer region of our planet where principal sources of energy and the vast majority of raw materials required for the construction, manufacturing and chemical industries are found. Recent investigation by the Nigerian Geological Survey Agency (NGSA) and private exploration/mining companies has continued to shed more light on the endowment. For instance, the Nigerian Extractive Industry and Transparency Initiative (NEITI) report suggest that there are over thirty (30) different kinds of solid minerals and precious metals buried in the Nigerian soil waiting to be explored.

Although efforts have been made by the Nigerian government to develop the solid mineral sector, such efforts have been relegated by the discovery of petroleum and its subsequent domination of the economy. In fact, the solid mineral sector which used to be the bedrock of



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Nigeria's economy before the discovery of oil is almost completely abandoned by the Nigerian government. However, as the hydrocarbon potentials of the prolific Niger Delta becomes depleted or may be exhausted in the near future due to continuous exploitation; And with the current economic recession resulting from the drastic fall of oil price in the world market, increasing emphasis has come to be placed on the potential importance of the solid mineral sub-sector of the Nigerian economy. This is due to the realization of the crucial role the solid mineral sector can play in the economic recovery of Nigeria. Adewumi and Salako (2017), stated that Minerals are of importance to the economy of a nation if discovered and harnessed [2]. The quest for diversification of the national economy and in particular, the importance attached to breaking the dominance of crude oil in the export structure of the economy has led to a focus on the sub-sector. The role which the development of solid mineral can play in accelerating economic, social and political growth of Nigeria needs no exaggeration. This is even more so now when the country is finding a lasting solution to her economic problems. Solid minerals sector is therefore the type of sector that must be developed in order to diversify the economy; as this will create a productive environment for business opportunities, boast the nation economy and provide raw materials for industrial uses which might in turn reduce the level of unemployment thereby eradicating poverty in Nigeria.

This paper therefore, seeks to investigate and/or delineate mineral potential zones over the lower part of Sokoto basin northwestern Nigeria by analysis and interpretation of aeromagnetic data maps of the area in question using first order vertical derivative, second order vertical derivatives, downward continuation, analytic signal and tilt derivative.

### 1.1 Geology and Location of the study area

Muhammad and Abdul-Fatah (2010), explained that the study area is part of the vast late Proterozoic-early Phanerozoic terrane separating the west African and Congo cratons [3]. It comprises the late Proterozoic metasedimentary rocks (mainly sericite-chlorite phyllite) intruded by a pan-African granodiorite batholith and an associated narrow contact aureole (50-350m) of mainly pelitic hornfels. Garba (1994), reported that the metasedimentary rocks belong to the Zuru schist belt, one of the many NNE-trending belts to the low grade (mainly greenschist faces) supracrustal rocks that are believed to have been deposited as proterozoic cover on older basement rocks [4].

The area is located in southwestern part of kebbi state, northwestern Nigeria and lies between latitude $10^0 5'00''$N and $11^0 5'00''$N and longitude $04^0 00''$E and $05^0 00''$E. It is accessible by road through Abuja (the Federal Capital|), via Minna-Kontagora-Mararraba and to Yauri. Figure 1 is the geological map of Nigeria showing the location of the study area:

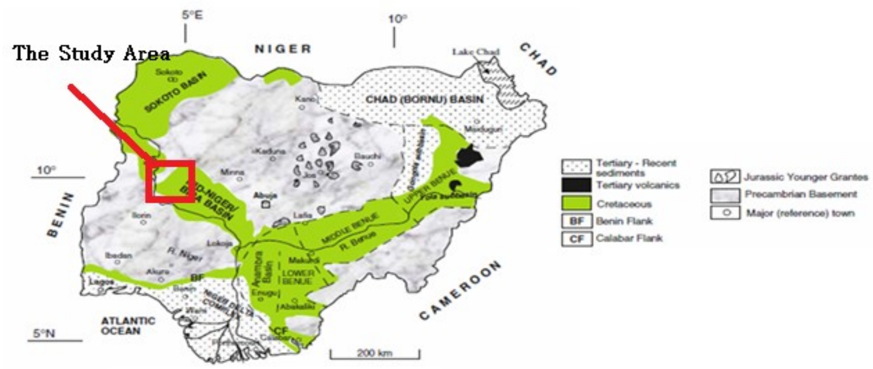


Figure 1. Geological map of Nigeria showing the study area (Obaje, 2004)

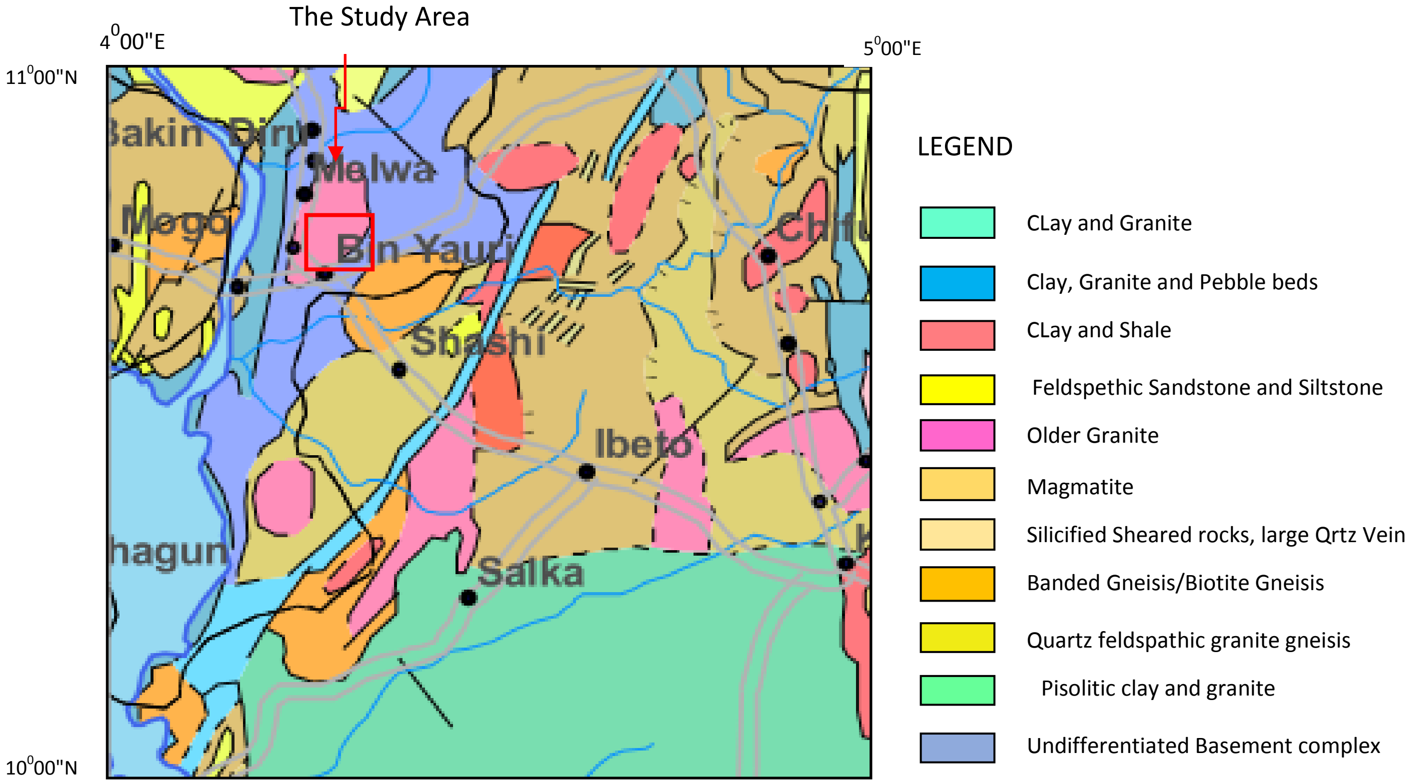


Figure 2: Geological map of the study area extracted from the Geological map of Nigeria

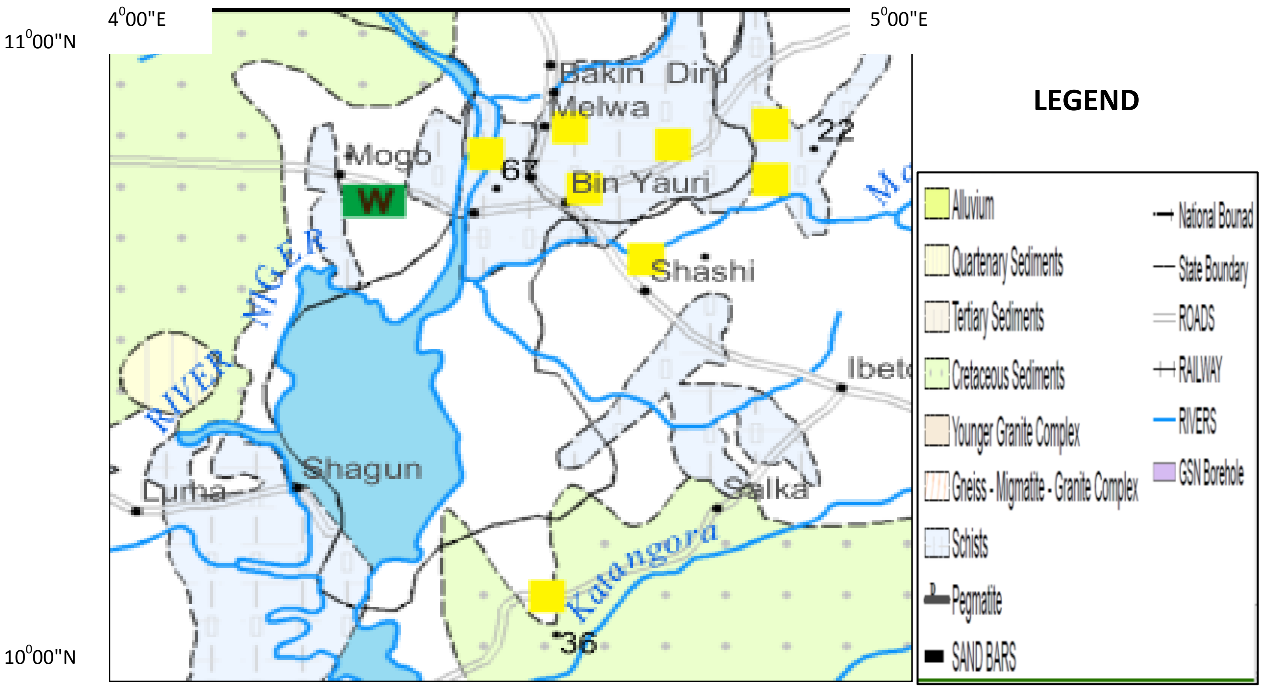


Figure 3: Major mineral Resource map of the study area extracted from the Mineral resource map of Nigeria

### 1.2 Major Mineral Resources of the Area

The most important economic mineral deposit in the area as described by Adetona *et al.* (2007) includes such industrial minerals as gold, clays, limestone, ironstone and laterites



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including radioactive minerals and salts [5]. The occurrence of gold and coal as well as ferruginized sandstone is wide spread throughout the area. This serves as a major source of raw materials for road construction and other industrial uses.

## 2. MATERIALS AND METHODS

### 2.1 Materials

Four high resolution aeromagnetic data sheets of total field intensity in $1/2^0$ by $1/2^0$ covering sheet 95, 96,117 and 118 corresponding to Ka´oje, Shanga, Konkwesso and Yelwa were acquired from the Nigerian Geological Survey Agency (NGSA), which is the agency that sponsored the nationwide airborne survey carried out by Fugro between 2013 to 2009. The data were obtained at an altitude of 100m along a flight line spacing of 500m oriented in NW-SE and a tie line spacing of 200m. The geomagnetic gradient was removed from the data using the international geomagnetic reference field (IGRF). The maps are numbered and names of places and coordinates (latitudes and longitudes) written for easy reference and identification.

In order to produce a unified map of the study area, the first step taken was to assemble the four maps covering the area. The map was then re-gridded to produce the total magnetic intensity (TMI) map of the study area using Oasis montaj software. The actual magnetic intensity value of 33,000nT which was reduced (for handling purpose) before plotting the contour map was added so as to get the actual value of the magnetic intensity at any point

### 2.2 Methods

**First and Second Vertical Derivatives**

The vertical derivative is commonly applied to total magnetic field data to enhance the shallow geological sources at the expense of the deep seated sources. Adewumi and Salako (2017), elaborated that the enhancement sharpens the edges of the anomalies over bodies and tends to reduce anomaly complexity allowing clearer imaging of a causing structure vertically. The vertical derivative is much more responsive to local influence than broad or regional effects, and therefore gives sharper picture than the map of total field intensity. First vertical derivative data has almost become a basic necessity in magnetic interpretation projects. In fact, the first vertical derivative is used to delineate high frequency features more clearly where they are shadowed by large amplitude low frequency anomalies. This is done using the Laplace transformation expression shown below:

$\nabla^2 \mathrm{f} = 0$……………………………………………………………………(1)

Where $\nabla^2 \mathrm{f}$ is the Laplace transform which can be expressed in full as:

$$\frac{\partial^2 f}{\partial z^2} = -\left[\frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}\right] \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$\partial x, \partial y$ *and* $\partial z$ are the differentials in x ,y and z coordinates

The nth vertical derivative can be computed using:

$\mathrm{F}\left[\frac{\partial^n f}{\partial z^n}\right] = k^n \mathrm{F}(f)$………………………………………………………….(3)

The second vertical derivative has more resolving power than the first vertical derivative. Apart from enhancing the shallower anomalies, the second vertical derivatives are also used to delineate geological boundaries between rocks with contrasting physical properties such as magnetic susceptibility. Labbo and Ugodulunwa (2007), stressed that the contoured second vertical derivative outlines the bodies causing the magnetic anomalies [6]. The second vertical derivative is based on equation 3.3 when $n = 2$

Where F is the Fourier representation of the field, k is the wave number or frequency, f is the input to be filtered

**Downward Continuation**

Downward continuation is used to enhance features at a specified depth/elevation lower than the acquisition level. Adewumi and Salko (2017), stressed that this procedure accentuates near surface anomaly and can be used as an interpretation to determine the depth to a causative body. The filter can be applied to both gravity and magnetic data. Downward continuation is done using the expression:

$$L(r) = \ell^{hr} \ldots \ldots \ldots \ldots \ldots \ldots \ldots (4)$$

Where h is the distance in meters to be continued down, r is the wave number in rad/ground unit.

**Tilt Derivative**

Tilt derivative and its horizontal derivative according to Marwan and Yahya (2017), are used for mapping shallow basement structures and mineral exploration targets [7]. In potential field images, tilt derivative has made the task of enhancing features and detecting causative body edges easier.

The tilt derivative filter is defined as:

$$\text{TDR} = \tan^{-1}\left(\frac{VDR}{THDR}\right) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (5)$$

Where VDR and THDR are the Vertical derivatives and Tilt horizontal derivatives of the total magnetic intensity respectively.

$$\text{VDR} = \frac{\partial T}{\partial z} \text{ and RHDR} = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2} \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

The total horizontal derivative of the tilt derivative is defined as the square root of the sum of squares of the tilt angle derivatives in the x and y directions and is mathematically defined as:

$$\text{Hence, THDR} - \text{TDR} = \sqrt{\left(\frac{\partial TDR}{\partial x}\right)^2 + \left(\frac{\partial TDR}{\partial y}\right)^2} \ldots \ldots \ldots \ldots \ldots \ldots (7)$$

**Analytic Signal**

The analytic signal is a notable method for establishing the edges of magnetic anomalies. It can be applied either in space or frequency domain, generating a maximum directly over discrete bodies as well as their edges. Ansari and Alamdar (2009), in Thabisani *et al.* (2015) highlighted that the analytic signal or total gradient is formed through the combination of the horizontal and vertical gradients of the magnetic anomaly [8]. Thabisani *et al., (*2015), also stated that its form over a causative body depends on the location of the body (horizontal coordinate and depth), but not its magnetization direction [9]. The simplification of magnetic data involves creating a function which is independent of body magnetization direction and ambient geomagnetic parameters. The analytic signal filter possesses this property and has been used for edge detection and depth estimation of magnetic bodies by several authors. Roest *et al.* (1992), applied it for detecting causative body location; Hsu *et al.* (1996), used it for geologic boundary edge detection [10], [11]. The filters ability to generate a maximum value directly over the causative body and depth estimation makes it a highly useful



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technique for magnetic data interpretation (Ansari and Alamdar, 2009) in Thabisani *et al.* (2015).

The amplitude of the analytical signal of the total magnetic field F is calculated from the three orthogonal derivative of the field defined as:

$$A(x,y) = \left(\frac{\partial M}{\partial X}\right)X + \left(\frac{\partial M}{\partial Y}\right)Y + \left(\frac{\partial M}{\partial Z}\right)Z \ldots\ldots\ldots\ldots\ldots\ldots..(8)$$

With M= magnetic field the analytical signalamplitude can now be written as:

$$|A(x,y)| = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial Y}\right)^2 + \left(\frac{\partial M}{\partial Z}\right)^2} \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

## 3. RESULTS AND DISCUSSION

### 3.1 Total Magnetic Intensity Map

The total magnetic intensity (TMI) map of the study area (Figure 4) was produced in color aggregate using Oasis montaj. The map shows variation in magnetic signatures of highs and lows ranging from a minimum value of -64.1nT to a maximum value of 123.6nT. The orange-pink colors on the color legend depicts areas with high magnetic signatures and light-dark blue colors represent low magnetic signatures while green-yellow colors indicate medium magnetic signatures.

Although the total magnetic intensity (TMI) map of the study area is magnetically heterogeneous, it is however clear that the high magnetic signature (61.9nT-123.6nT) which implies basement complex, is more pronounced at the central part of the study area, trending east-west; With few traces of high magnetic signatures scattered virtually all over the area. The low magnetic signature (-64.1nT-35.1nT) is more prominent at the northern and southern parts of the study area corresponding to Ka'oje and some parts of Shanga, Konkwesso and Yelwa trending NE-SW while the medium magnetic intensity (38.4nT-60.0nT) which indicates alluvium deposition can be found virtually all over the area. The map also revealed NE-SW structural alignments which may probably be the host for minerals such as gold, uranium, tantalite, tourmaline etc

### 3.2 Vertical Derivatives Maps

The first vertical derivative map (figure 5a) comprises of basement and sedimentary regions. The northeastern and southwestern parts of the map are dominated by high intensity and consequently shallow magnetic bodies (basement complex) embedded in a smoothly varying background which indicates sedimentary intrusion upon basement complex. The two portions of the map are separated diagonally by a region of medium intensity depicted by green-yellow colors which may represent alluvium deposits. The map also revealed presence of structures (lineament) aligned in NE-SW. Since structures (lineaments) are known to be good hosts for magnetic minerals, the structures found on the map might favor the mineral the accumulation in the area.

Similar to the first vertical derivative map, the second vertical derivative map (figure 5b) shows more clearly, the magnetic anomalies and discontinuities oriented in the NE-SW direction. The map revealed clearer image of the geologic features such as faults and veins present in the study area. Since minerals are mostly structurally controlled, the trend of structures (faults and veins) delineated on the second vertical derivative map may imply/ reflect the alignment of minerals like gold, tourmaline and tantalite around Shanga, Yelwa and Konkwesso.



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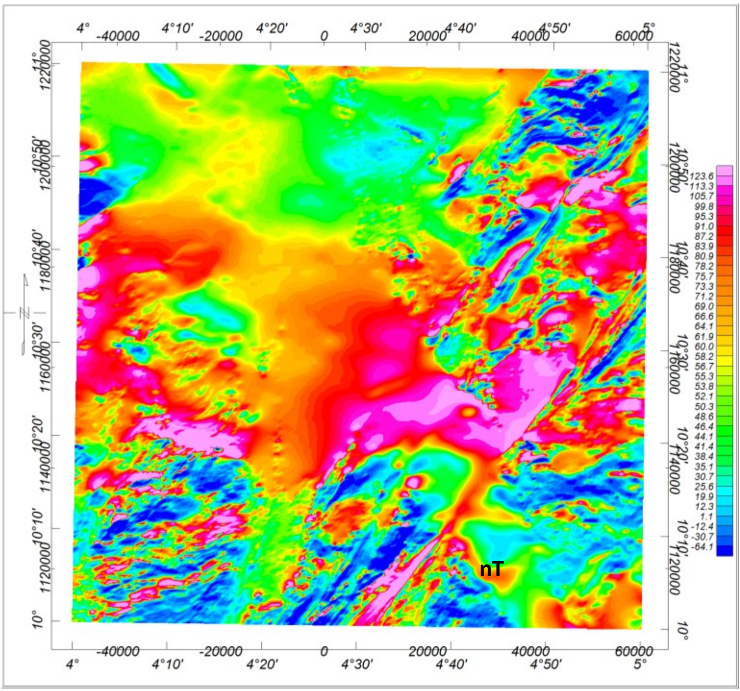
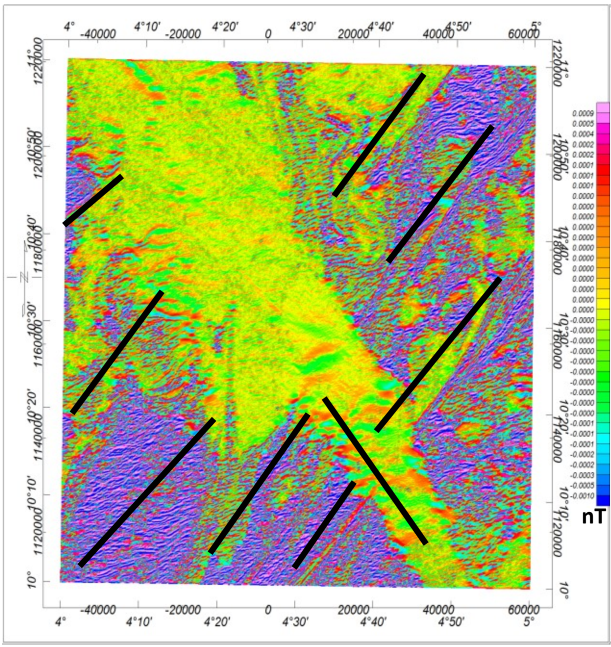



Figure 4: Total Magnetic Intensity Map of the study area



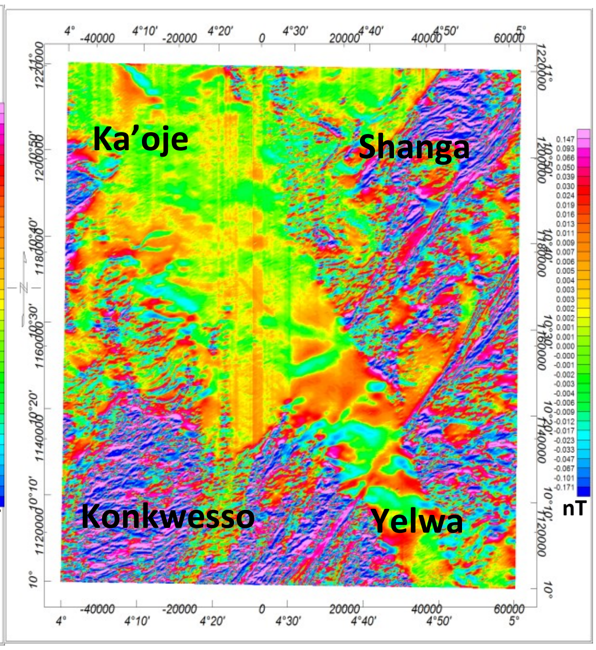




**Fig.5a:** First Vertical Derivative Map. **Fig. 5b**: Second Vertical Derivative Map

### 3.3 Comparison of Lineament Map with First Vertical Derivative Map

Figure 6a is the lineament map of the study area extracted from the lineament map of Nigeria produced by the Nigerian Geological Survey Agency (NGSA) IN 2005 while Figure 6b is the first vertical derivative map of the study area produced using Oasis Montaj software. Careful inspection of the two maps shows that there is conformity in the manner by which the features (lineaments) are aligned. On both the two maps, features like cracks, faults and veins are present and are aligned majorly in NE-SW direction. It is also clear that the geologic contact present at the southwestern part of the lineament map is also present on the first vertical derivative map as indicated by the red arrow. Hence the first vertical derivative map, agree to a certain extent with the lineament map.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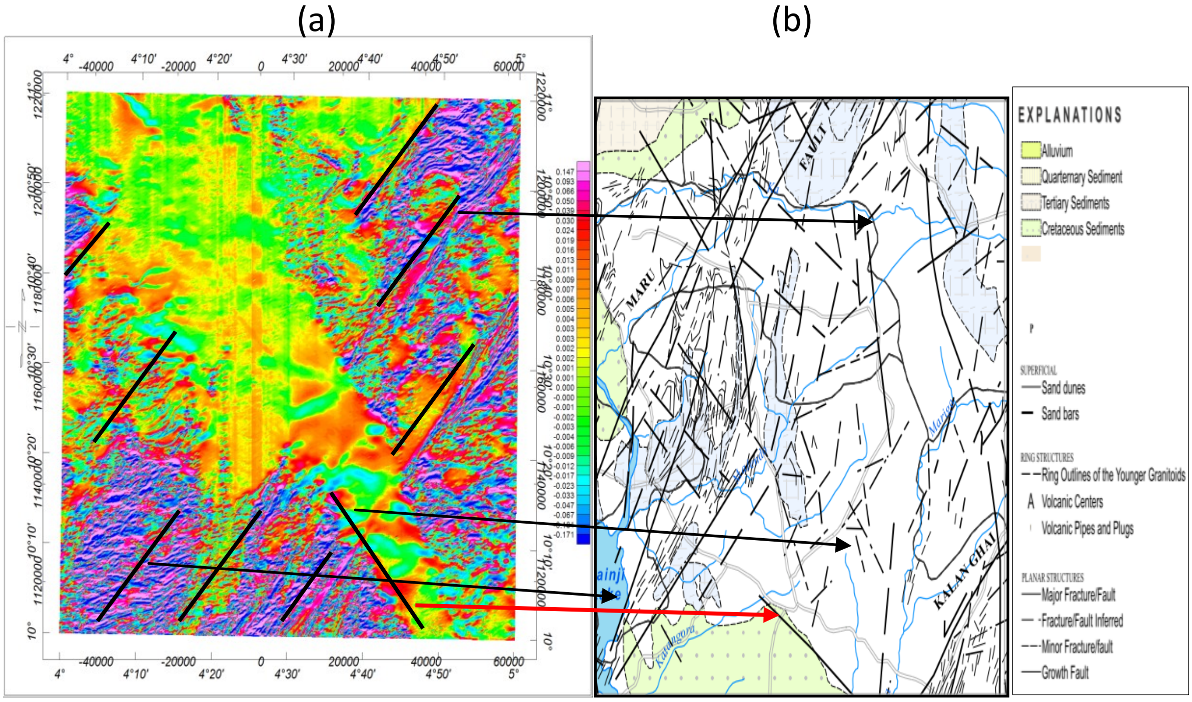


Figure 6: Comparison of lineament map with the first vertical derivative map

### 3.4 Downward Continuations of TMI Map at 50m

The total magnetic intensity map of the study area was downward continued at the height of 50m below the fight level in order to emphasize the near surface anomalous features present in the study area (figure 7). At the height of 50m, the total intensity map is slightly refined

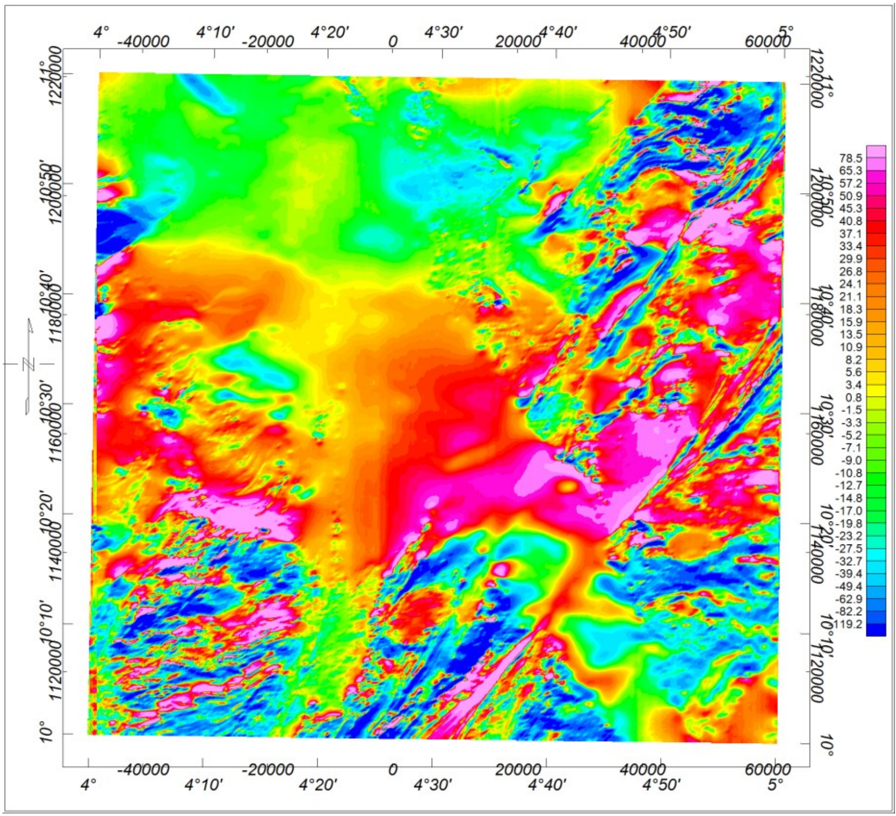


**Figure 7: Downward Continuation Map at 50m**

there by making the short wavelength (high frequency) anomalies more visible.

Just like the vertical derivatives maps, the downward continuation map revealed that the northeastern and southwestern is dominated by magnetic highs. Similarly, the faults and veins where magnetic minerals such as gold and granite are known to settle along igneous and metamorphic rocks are equally more pronounced at the northeastern and southwestern parts of the map which correspond to Shanga, Konkwesso and Yelwa. The northwestern part of the map corresponding to Kaoje and some parts of Shanga is characterized by sedimentary terrain which may also play host for minerals like clay and quartz.

### 3.5 Analytic Signal Map

With analytic signal, it is now possible to isolate weak anomalies resulting from the subdued magnetic sources occurring within the sedimentary strata. Hence, analytic signal provides an easy means of defining boundary edges between magnetic sources with contrasting anomalies.

Figure 8 is the analytic signal map of the study area. The map shows clear demarcation between high and low intensity sources. The high intensity magnetic signature (orange-red-pink colors) is more pronounce in the eastern and southwestern part of the study area corresponding to Shanga, Yelwa and Kwankwesso which are the areas with mineral potential while the low intensity signature (light-deep blue colors) associated with relatively good sedimentation, is more prominent in the northwestern part of the area which corresponds to Kaoje. Generally, the map agreed well with both the vertical derivative maps and the downward continuation maps in terms of the observed structural orientation and anomalous distribution over the area but the structures have been sharpened and made more clearly visible on the analytic signal map than it appeared on the vertical derivatives and downward continuation maps because many obscured anomalies are now brought to focus.

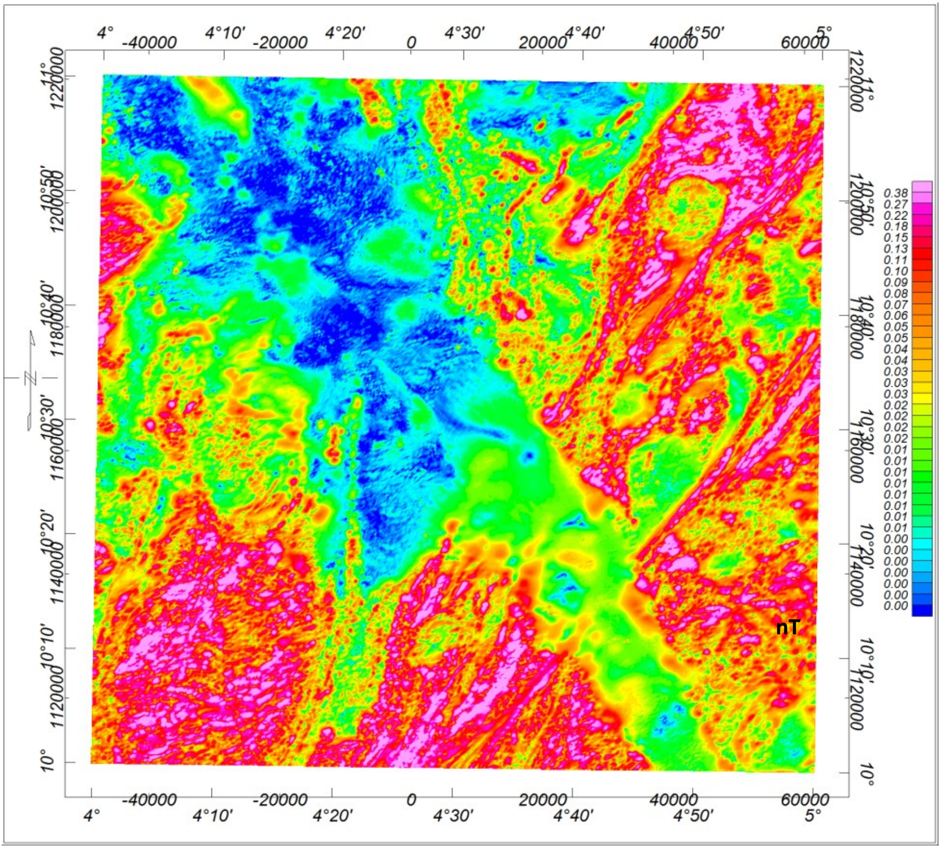


**Figure 8: Analytic Signal Map of the Study Area**

### 3.6 Tilt Derivative Map

The tilt derivative is particularly valuable in amplifying orientations of magnetic sources. Hence it can be used to identify structures capable of hosting minerals. The tilt derivative map (figure 9) revealed a more amplified image of the anomalous features (lineaments) in the study area. The map clearly shows that the area is fragmented by features such as outcrops, faults, cracks, fractures and joints which makes it a good site for mineral exploration target.

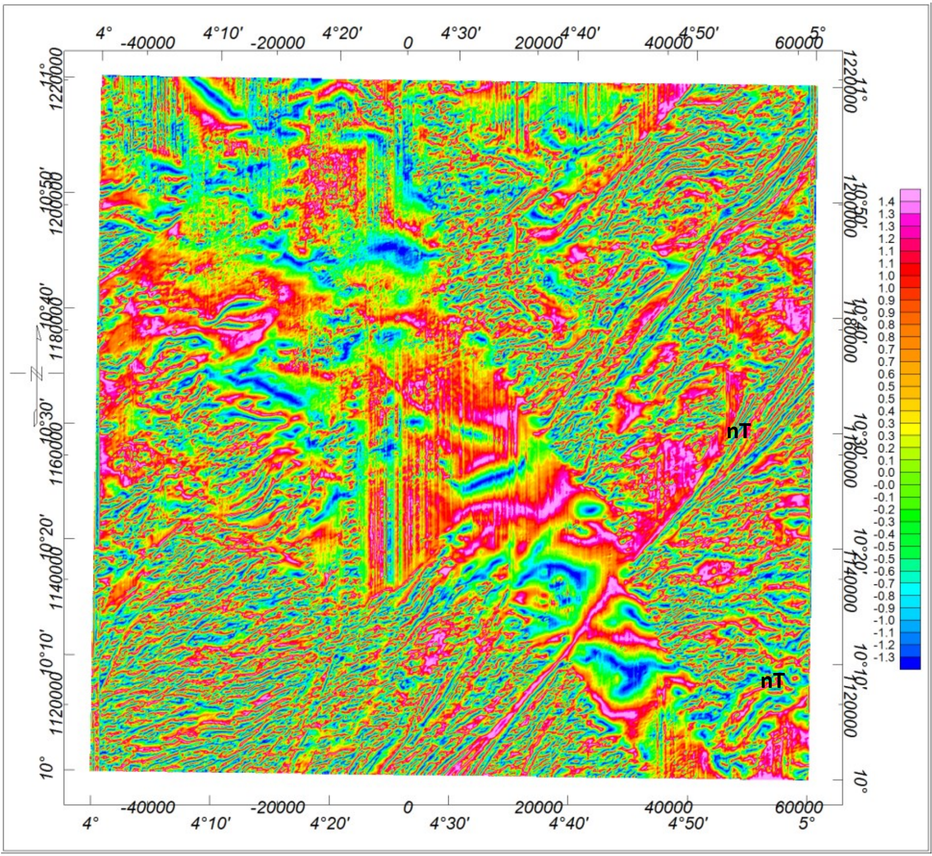

**Figure 9: Tilt Derivative Map of the Study Area**

## 4. CONCLUSION

Aeromagnetic data over the lower part of Sokoto basin northwestern Nigeria was qualitatively analyzed and interpreted with the aim of delineating mineral potential zones. The result led to delineation of NE-SW trending features such as fractures, faults and veins within which economic minerals mostly settle. The result also revealed regions within the study area where such minerals can be located and extracted. The northeastern and southwestern parts of the study area corresponding to Shanga, Konkwesso and some parts of Yelwa are regions dominated by basement complex, which may play host for economic minerals like Gold, Tourmaline, Tantalite and Granite e.t.c confined along the identified faults, fractures and veins.

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