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Original Research Article

Interpretation of Aeromagnetic Data over Part of Malumfashi Area, Northwestern Nigeria

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Abstract

This work is aimed at interpreting the Aeromagnetic data over Malumfashi area of Northwestern, Nigeria to delineate structures responsible for emplacing mineral deposits in the area. The Aeromagnetic data was interpreted qualitatively and quantitatively using Oasis montaj version 6.4. First vertical derivative, Analytical signal, Source Parameter Imaging (SPI), Potent dyke analysis and Euler deconvolution interpretation techniques were applied in the study. Analytic signal map revealed The qualitative interpretation applied helps enhance linear features at the expense of deep intrusive bodies like lineaments and fault zones which trend Northeast Southwest (NE- SW) in the study area and also indicated distinct pattern of magnetic signatures independent of magnetization direction with amplitude ranging from 0.01 – 0.30 nT/m. The upward continuation performed at 2 Km sharpened clearly the edges of the anomalies of geological interest. Depth obtained by SPI ranged from 161.142 to 576.339 m, this gives approximate depth to source of magnetic signatures in the area. Deep-seated and shallow bodies are observed in the Western and Eastern parts respectively of the area. The depth obtained for the potent dyke analysis is approximately 1000 m with susceptibility value of 0.0100 SI signifying Marble. The relative strike angle of the Dyke Model is (-56.2 degrees), this depth value for potent Dyke analysis agrees considerably with the depth values obtained for Euler deconvolution having a depth range of 149.2 to 1155.5 m. Conclusively, it is suspected that those linear features trending northeast southwest in the area are the potential structures for the emplacement of mineral deposits such as marble.

Keywords: Aeromagnetic data, fault zone, intrusive, strike angle, susceptibility.

INTRODUCTION

The Earth and its contents have long been of concern to mankind, Man has tried to unravel its complexity and develop into its origin via various geophysical methods. The subsurface has been of particular concern to geoscientists, who seek to investigate it using diverse means, some for the purpose of having knowledge, while others do it for exploration of economic resources such as minerals and hydrocarbons. With the advances in technology and the need to have a clearer picture of the earth subsurface and its contents, the earth scientists have deemed it necessary to utilize the properties associated with earth's interior. Geophysics involves application of physical principles and quantitative physical measurements to study the earth's interior, most often for economic purposes. Of all the available geophysical methods of investigations, the magnetic method, is most widely applied [1]. Regional or detail magnetic survey has continue to be a primary mineral exploration tool in the search for diverse commodities such as minerals and other geological structures having potential to host mineralization. This is largely due to the relative ease and cheapness in acquiring magnetic data. Aeromagnetic data has been used for several purpose such as mineral exploration, oil and gas exploration [2-4]. Since most of this mineralization are structurally controlled, this work will help establish a link between lineaments inferred on the field and the zone of mineral deposits across the study area.

Geology of the Study Area

The study area (Malumfashi) Northwestern Nigeria is on aeromagnetic sheet (79), located in the Nigerian basement complex between Latitude 11° 30' – 12° 00' N and longitude 7° 30' – 8° 00' E. Both the crystalline complex and the belts of younger meta-sediments of richly potassic syntectonic to late tectonic granites and granodiorites has intruded both the basement and its cover, this is evident from the works of McCurry [5], which reveal that the Kalangai fault is poorly exposed along its southern end around

Malumfashi and is probably an ancient fault which has reactivated several times. These granites are believed to be the product of widespread mobilization and reactivation of the crystalline complex during the pan African orogeny. They have effected contact metamorphism where they intrude part of the metasedimentary belts [6]. Jointing, fracturing and faulting followed the orogeny, and a major northeast-southwest transcurrent fault system crosses the area. It is obvious from the structural and metamorphic evidence that the pan African event reached the status of an orogeny in northwestern Nigeria [6].

MATERIALS AND METHODS

High Resolution Aeromagnetic (HRAM) data of Malumfashi (Sheet 79), which covers the area under consideration, was obtained from the Nigerian Geologic Survey Agency (NGSA). The data which is in half degree sheet, was compiled from the data collected at a flight altitude of 80 m, along NE-SW flight lines with approximate spacing of 500 m. The residual anomaly was separated from the regional magnetic field by using the polynomial fitting method for all the values in the grid. Nettleton [7] the residual anomaly data was interpolated using a minimum curvature gridding algorithm, available in the Geosoft Oasis Montaj (version 6.4) Module, with a grid cell size of 250 m. First vertical derivative, Analytic signal, Upward continuation, Source parameter, Euler deconvolution and potent dyke analysis were applied on the residual magnetic field grid in order to aid interpretation. The filtering techniques were selected because they best support the research interest of the work. The techniques include.

Vertical Gradients

Vertical gradient of potential fields are also a mainstay of the interpretation process, principally because they sharpen the response of geophysical features. This filtering method is effective in enhancing anomaly due to shallow sources; it narrows the width of anomalies and also very effective in locating source bodies more accurately [8]. In the frequency domain they can be calculated using [9].

$$A'(f) = A(f)|f|^n \quad \text{.................................} \ (1)$$

Where *A (f)* is the amplitude at a frequency *f*, and *n* is the order of the derivative.

Vertical derivatives are a measure of curvature, and large curvatures are associated with shallow anomalies. Thus, it enhances near-surface features at the expense of deeper anomalies.

The first vertical derivative (FVD) are given as:

$$FVD = \frac{\partial M}{\partial z} \quad \text{.........................} \ (2)$$

Where *M* is the potential field anomaly. The vertical derivative was computed from the upward continued data. This is very important to this research as it will bring out the lineaments of interest more obvious.

Upward Continuation of Residual Field

This is a mathematical technique that projects data taken at an elevation to a higher elevation. It is a filtering technique that removes noise caused by high frequency (i.e. short wavelength) anomalies which usually arise from near surface cultural features in the survey area. It accentuate anomalies caused by deep sources at the expense of anomalies caused by shallow sources [10]. The upward continued ΔF (the total field magnetic anomaly) at higher level (z = - h) is given by:

$$\Delta F\ (x, y, -h) = \frac{h}{2\pi}\iint \frac{\Delta F(x,y,0)dxdy}{((x-x_0)^2+(y-y_0)^2+h^2)} \quad \text{..........................} \ (3)$$

The empirical formula [11] gives the field at an elevation h, above the plane of the observed field (z = 0) in terms of the average value ΔF at the point (x, y, o). Generally, deep-seated magnetic sources are considered to have a low spatial frequency equivalent to large lateral extent or long wavelengths and broad anomalies; while near-surface or shallow magnetic sources result in a high spatial frequency corresponding to short lateral distance or short wavelength and narrow anomalies [12]. The Oasis montaj software is used to upward continue the residual field to a height of 2 Km.

Analytic Signal

The analytic signal technique is based on the use of the first derivative of magnetic anomalies to estimate source characteristics and to locate positions of geologic boundaries such as contacts and faults. The amplitude of Analytic Signal (AS) is defined as the square root of the squared sum of the vertical and the two horizontal first derivatives of magnetic field anomaly T and is given by [13].

$$A(x, y, z) = \frac{\partial T}{\partial x}\hat{x} + \frac{\partial T}{\partial y}\hat{y} + i\frac{\partial T}{\partial z}\hat{z} \quad \text{..............................} (4)$$

Where $\hat{x}$, $\hat{y}$ and $\hat{z}$ are unit vectors in the x, y and z directions, respectively $\frac{\partial T}{\partial z}$ is the vertical derivative of the magnetic anomaly field intensity, $\frac{\partial T}{\partial x}$ and $\frac{\partial T}{\partial y}$ are the horizontal derivatives of the magnetic anomaly field intensity. The above equation satisfies the basic requirement of the analytic signal, that is real and imaginary parts form a Hilbert transform pair [14].

The amplitude of the analytic signal in 3D is given by:

$$|A(x,y,z)| = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2} \quad \text{...........................} (5)$$

Expression of the amplitude of the analytic signal gives a function that produces maxima approximately over the edges of the magnetic body source.

One advantage of the Analytic Signal technique is that it defines source positions regardless of any remnant magnetization in the sources [15], hence it's independent of the direction of magnetization. Maxima (ridges and peaks) in the calculated analytic signal of a potential field anomaly map locate the anomalous source body edges and corner.

Source Parameter Imaging Method

This was also employed in this work to estimate the depth from the local wavenumber of the analytical signal. The analytical signal A_1 (x, z) is given as [16, 17]:

$$A_1(x, z) = \frac{\partial m}{\partial y}(x, z) - j\frac{\partial m}{\partial x}(x, z) \quad \text{................................} (6)$$

Where m (x, z) is the magnitude of the anomalous total magnetic field, j is the imaginary number, while x and z are Cartesian coordinates for the vertical and horizontal directions, respectively.

Euler Deconvolution

The Euler Deconvolution is a 3-Dimensional semi-automatic interpretation technique widely used in depth estimation and delineation of a wide variety of geologic structures. It is based on Euler homogeneity equation (7) which relates the potential field (magnetic or gravity) and its gradient components to the location of the sources, by the degree of homogeneity N, interpreted as a structural index [18].

$$(x - x_o)\frac{\partial T}{\partial x} + (y - y_o)\frac{\partial T}{\partial y} + (z - z_o)\frac{\partial T}{\partial z} = N(B - T) \quad \text{...........................} (7)$$

Where T is the total field at (x, y, z) and B is the regional value and N is the structural index. Assuming various measurement point and known N, the above equation can be solved with least squares procedure for unknowns x_0, y_0, z_0 and B. An important parameter in the Euler equation is the structural index N. This is a homogeneity factor relating the magnetic field and its gradient components to the location of the source. A poor choice of the structural index has been shown to cause a diffuse solution of source locations and serious biases in depth estimation. Both Thompson [19] and Reid *et al.*, [20], suggested that a correct N gives the tightest clustering of the Euler solutions around the geologic structure of interest. Thompson [19] gives more detailed discussion on the degree of homogeneity of potential fields and structural indices of Euler Deconvolution.

RESULTS AND DISCUSSION

Qualitative Interpretation of Results

The regional map of the study area is shown in Figure-2**.** Regional field values Figure-2 which are large features that generally show up as trends and are caused by deeper homogeneity of the earth crust was removed from the total magnetic intensity grid by the method of least squares approach using polynomial fitting method showing regional field values ranging from 32972 to 33002 nT. The left over in the gridded data after removing the regional field is the residual field (Figure-3) caused by high frequency shallow anomalies which corresponds to the location of the target anomalous bodies like structures with magnetic intensity values ranging from -99.112 to 79.831 nT**.**

This residual field is further subjected to various qualitative and quantitative interpretations such as first vertical derivative, upward continuation, analytical signal and Tilt Derivative. First vertical derivatives were used in this research to enhance the upward continued field data, the first vertical derivative map is shown in Figure-4 and its lineament orientation in Figure-10 which corresponds to response of the target structures with magnetic intensity field value ranging from -0.145 to 0.134 nT/m. The residual field was subjected to upward continuation at 2Km, this helps remove noise caused by high frequency shallow anomaly. The upward continued field map is shown in Figure-5 with field intensity range of -51.819 to 43.997 nT. The analytic signal map produced gives distinct pattern of magnetic signatures in the area, with magnetic intensity of 0.02 to 0.32 nT/m. The result shows the continuation of the inferred Kalangai fault known to trend N-S in the area as evident from the work of McCurry [21]. The map shows high analytic signal amplitude most prominently around the eastern flank, with medium to low analytic signal along the western part of the area as illustrated in Figure-6.

Quantitative Interpretation results

In this work, we applied the Source Parameter Imagine method (SPI) and Euler method on the Residual Magnetic Intensity grid using the Euler 3D extension module of the Oasis Montaj software. Depth obtained by source parameter imaging (SPI) ranged from 161.142 to 576.339 m. Results from this study indicate that deep seated bodies are predominant in the Western part of the area, while shallow bodies are predominant in the Eastern part of the area as shown in Figure-7. For Euler solutions, the best clustering solution was obtained by selecting a structural index of one (i.e. SI = 1) (Figure-8). Shows that the solution plotted clustered in the region where the geological structures are located figure-8 shows average depth range of 149.2 to 1155.5 m. The anomalies over the area were modeled by bodies in the form of Dyke by varying the total magnetic intensity parameters. Depth obtained by the potent Dyke analysis is 1000 m with susceptibility value of 0.0100 SI signifying a metamorphous limestone (marble). The relative strike angle of the Dyke Model is (-56.2 degrees). The Dyke geometry map is shown in Figure-9.

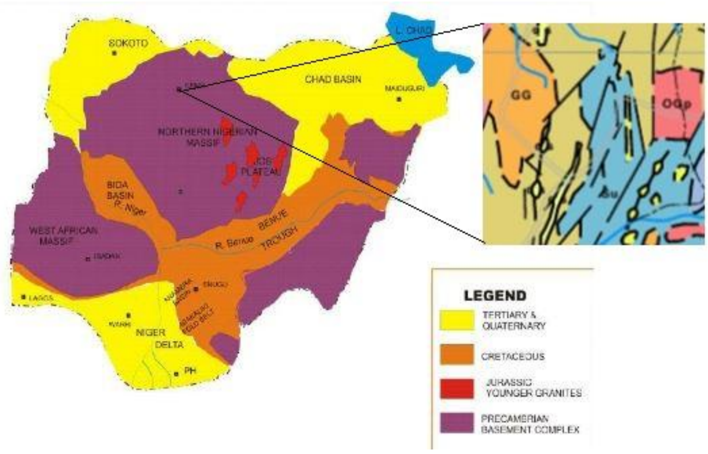

Fig-1: Geological Map of the Area

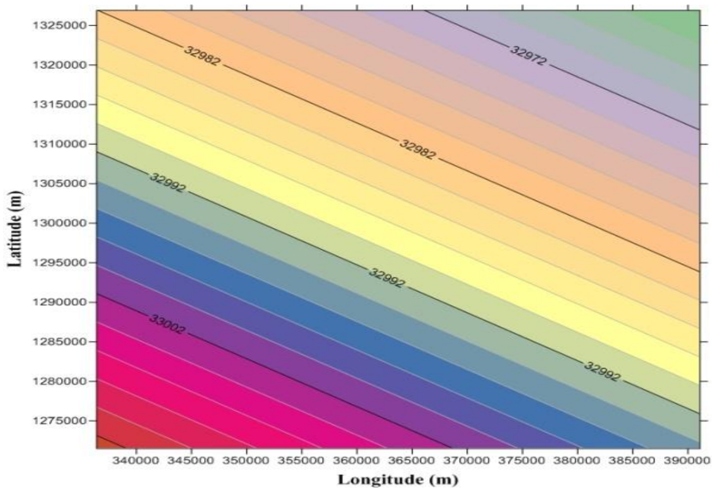

Fig-2: Regional field map of the area

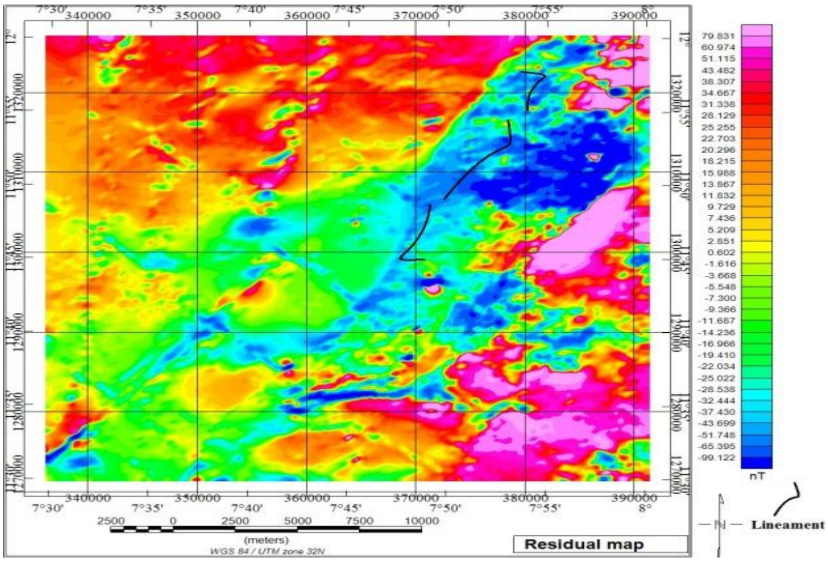

Fig-3: Residual map of the area

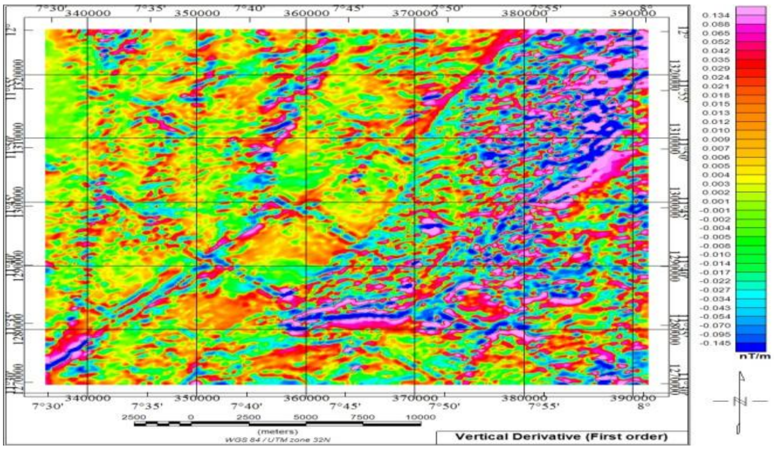

Fig-4: First vertical derivative map

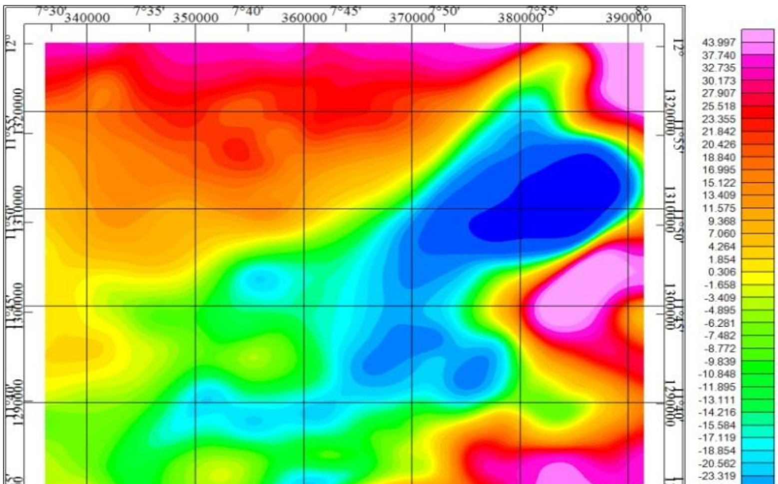

Fig-5: Upward continuation map

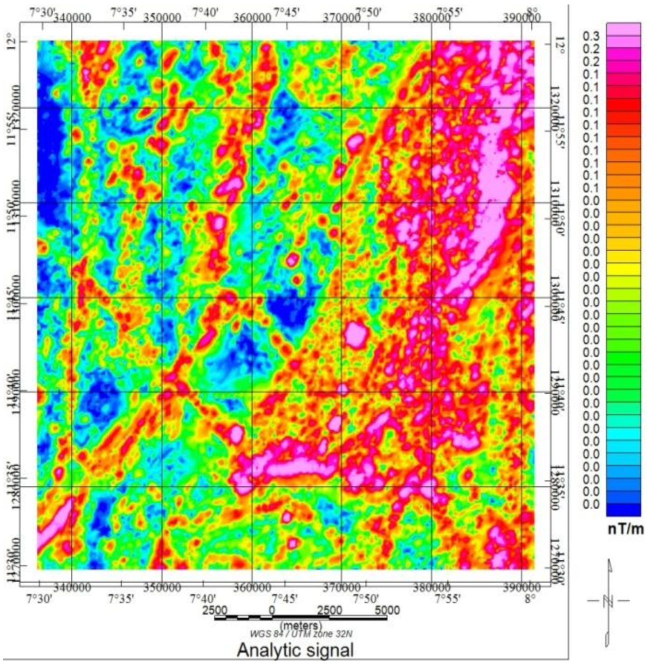

Fig-6: Analytical signal map of the area

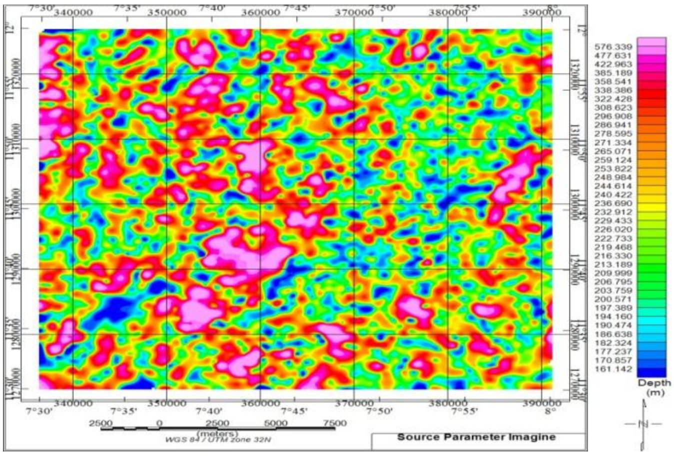

Fig-7: Source parameter map

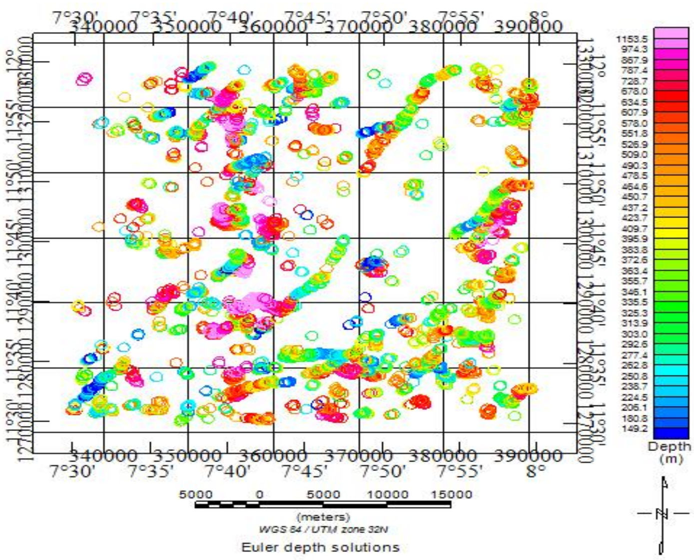

Fig-8: Euler depth map

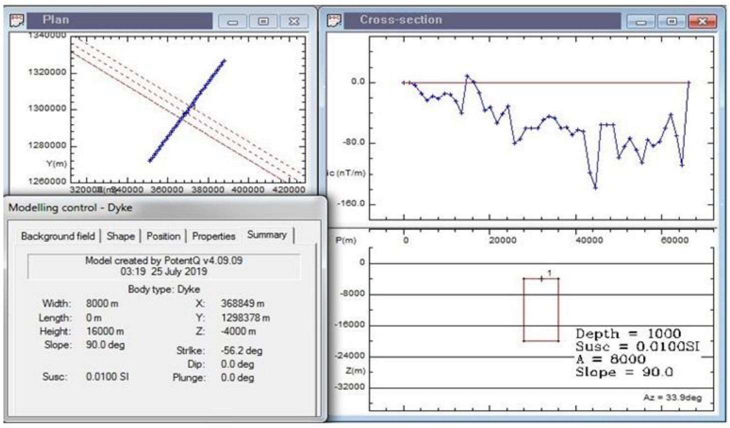

Fig-9: Dyke geometry map

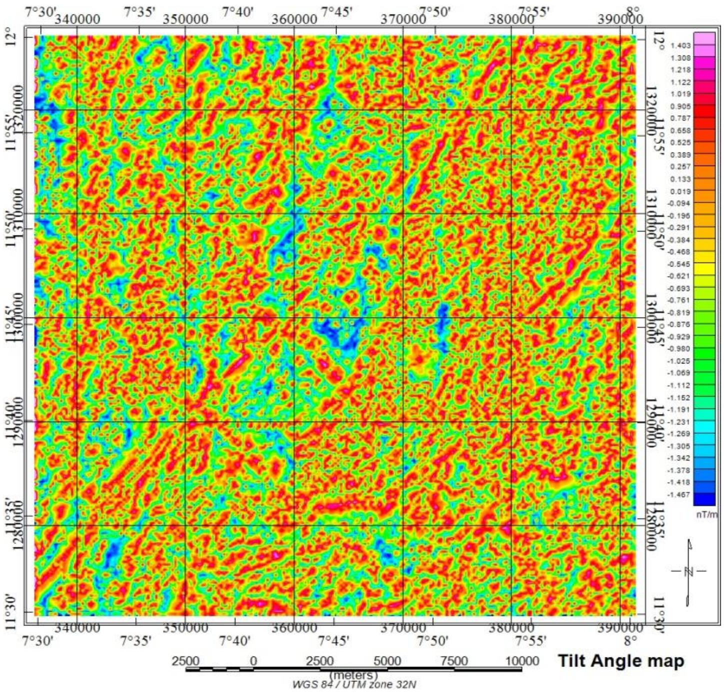

Fig-10: Tilt Derivative Map

CONCLUSION

In conclusion, the qualitative interpretation unveiled intrusive bodies like structures, in the area. It also revealed the possible continuation of the Kalangai fault which trends Northeast Southwest in the study area, it is marked by quartz ridges, its poorly exposed along its southern end and is probably an ancient fault which has reactivated several times during the pan African orogeny as evident from the works of [6]. Quantitative interpretation carried out for source parameter imaging, potent dyke analysis and Euler deconvolution methods, shows Depth obtained by source parameter imaging (SPI) ranging from 161.142 to 576.339 m. while depth values for the euler depth analysis shows average depth range of 149.2 to 1155.5 m. Depth obtained by the Dyke model is 1000 m with susceptibility value of 0.0100 SI signifying Marble. This depth value for the potent Dyke analysis agrees considerably with the depth values obtained for Euler deconvolution and as such is an indication that the structures responsible for hosting these minerals are deeply seated.

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