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Subsurface Investigation of Western Part of Zamfara Using Aeromagnetic Data

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ABSTACT

The study area falls within the basement complex of northwestern Nigeria and covers four adjacent quarter degree sheets of Gandi (sheet 30), Kauran namoda (sheet 31), Anka (sheet 52) and Maru (sheet 53),which covers the area under consideration. some of the published geophysical investigation on mineralization in the area used the old aeromagnetic data with relevant techniques. Hence with the provision of high resolution aeromagnetic data sets, subsurface investigation survey needs to be carried out in order to identify more areas of possible mineral deposit. Nigeria depend or operates on petroleum based economy, however , as gradually the petroleum is devaluating due to continuous exploitation , it is income to the country . Solid mineral sector has been one of the high income earners for many countries. The aim and objective of this research is to delineate and identify the mineralization zones in the basement complex in western part of Zamfara in Nigeria. This was achieved by determining depth to basement, producing a total magnetic intensity map showing magnetic susceptibility range across the entire study area, and a model of the shape, location and depth of structures in the study area. The anomalies on the aeromagnetic map were defined by fitting a first order polynomial to the total fields, by the method of least squares to obtain the residual field data. First vertical derivative and analytic signal computed, defined distinct pattern of the magnetic signatures. Depths to the surface of the geologic structures were obtained from Euler deconvolution solutions which gives an average depths range of248.28 m to 1679.57 m, with very few solutions having depths less than 300 m. The most prominent lineament and all major subtle lineaments have a depth range of 200 m to 600 m which shows that the structures are deep seated.

I. INTRODUCTION

A Mineral is a naturally occurring in-organic solid with a definite chemical composition and an ordered atomic arrangement. Mineral are natural resources that form part of the earth resources which is based on human race for exploitation, extraction and utilization(Oxford science Dictionary, 2010). Mineral are naturally raw material that the country depend on for their source of income. The world depends on natural resources located in the earth crust in the outer region of the earth internal structure where principle sources of energy and raw material required for manufacturing industries in this country Nigeria are located. Adewumi & Salako (2017) stated that the Minerals are of great importance to the economy of the nation if discovered and harnessed. This will create a productive environment for business opportunities, boost the nation economy and provide raw materials for industrial uses which might in turn reduce the level of unemployment by eradicating poverty in Nigeria. Nigeria is endowed with variety of such resources, so many are yet to be explored, the Nigerian extractive industry and transparency initiative (NEITI) 2016 report suggested that there are over 30 different kinds of solid Minerals and precious metals buried in the Nigeria soil waiting to be explored. Nigeria has long history of mining and exploitation.

The mining of the solid Minerals in Nigeria started in (1901) when many European companies show their interest and organize mining of tin around Jos and later move to the other part of the country. All the mining works was by the colonial officers. December 1903 official in geophysical surveys when the colonial government inaugurated the mineral survey committee. The committee was to carry out a reconnaissance survey of the mineral of the southern and northern protectorates before undertaking on the more detailed and more expensive task of geological mapping of the regions. The outcome of the survey the discovery and documentation of the lignite bodies of Asaba-ibusa-ogwashi environs, occurrences of galena, tinstone, columbine, monazite, limestone and clays in various localities of southern Nigeria.

Daniel et al. (2015) discover that over 80% of the country`s revenue comes from export and domestic sales of oil and gas. However, as the hydrocarbon investigation 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 in oil price in the world market, the Nigerian government is now making a tremendous effort to diversify the economy with emphasis on agriculture and mining. This is due to the realization of the crucial role the solid mineral sector can play in the economic recovery of Nigeria

In northern Nigeria contributions include location of some occurrences of iron-ore near lokoja marble close to Jakara and tin in some parts of kabba Ilorin and Zaria in 1909, coal was discovered along the udi escapement as the major output of the mineral survey of southern Nigeria. Exploitation effort was made with the setting up of the geological survey of Nigeria and the subsequent disbanding of the regional mineral surveys. The activities of the geological survey of Nigeria during the world war II was mainly in search of strategic minerals such as wolframite and tantalite in pegmatite’s of central Nigeria and further on tin and columbite of plateau. The post war period witnessed a change in orientation which was geared towards control, order and supervision in the sector, hence the enactment of the mineral act of 1946. Efforts were also concentrated on solid Mineral fuels notably coal seemingly required as energy sources for industrial and economic propagation. This increased political awareness, prompted the then British government to set up a commission of enquiry which recommended that independent bodies be set up to manage government established business. In 1950, by the ordinance number 29, the Nigerian coal corporation was created and charged with the responsibility to prospect, mine, treat and market coal by-production in Nigeria thus coal product in Nigeria. Thus coal production attained a peak value of about million tons per year by 1952-1957 and became one of the major foreign exchange earners for the then British colony. In 1960 when the country got independence, the activities of geological survey of Nigeria was intensified to examine and assess several occurrences of valuable Minerals. In 1964 and 1967, government enacted the explosive act and regulation which regulates the importation of explosives, Manufactures, storage, Transportation, sales and use of explosives. The quarries of decree of 1969 regulate the issuance of licenses and leases for the exploitation of all naturally occurring minerals. The ministry of mines and steel development (MMSD 2010). In 1970-1974 plan period, in this period; direct government participation in the sector began with the establishment of the Nigeria mining corporation (NMC) in 1972 to prospect for mine, refine and deal in all minerals except coal (which all long has been mined only by the government –owned Nigeria coal corporation).

All newly discovered minerals are vested in the Nigeria mining corporation (NMC) and no further concessions were granted to private enterprise. In addition to direct participation during the plan period, government also under took extensive mineral survey, exploration and mineral deposit appraisals. Also effort to develop the sector was made during the 1990-1992 rolling plan period. Based on governments ongoing re-establishment of the Nigeria economy and wide frame work of the 1986 industrial policy of Nigeria encouraged investments and promoted a greater private sector participation in exploration and mining operations.In1995 the ministry of solid minerals development was established by the government in order to enable the sector have necessary attention needed (MMSD 2010). Although efforts have been made to develop the sector, but have relegated to the background with the discovery of petroleum. The sector has always been an appendage of one ministry or the other where it received little or no attention. Inadequate funding has always been its lots while poor staffing and absence of a national mining policy further compounded the problems of the sector. Also in the recent past the sector has witnessed so much undue interference and usurpation of powers of the federal government with regards to solid minerals exploitation from states and local government authorities. Such a situation has proved detrimental to smooth operations in the mine fields. The discovery of petroleum and its subsequent domination of the Nigerian economy also contributed to the lack of attention of mineral exploration despite the wide speed investigation. In facts the solid mineral sector which used to be bedrock of Nigeria`s economy before the discovery of oil is almost completely abandoned by the

Nigerian government, this in-turn pave the way for further research of this nature to foster and reveal possible locations and abundance of these resources in the country.

1.2 location of the study area

The study area with sheet numbers 30(Gandi), 31(kauran namoda), 52(Anka), 53(maru) is located in the basement complex northern Nigeria and lies between latitude 12N to 13N and longitude 5.5E to 6.5E, the area is western parts of zamfara Nigeria it forms part of the northern Nigerian basement complex which was effected by the pan-African orogeny. the study area is considered to be upper proterozoic supracrustal rocks which have been infolded into the migmatites-gneiss-quartzite complex, pelitic rocks are dominant within the study area, mainly as pyllites and slates interlaminated with siltstones. Banded iron formation, containing magnetite, hematite and garnet.

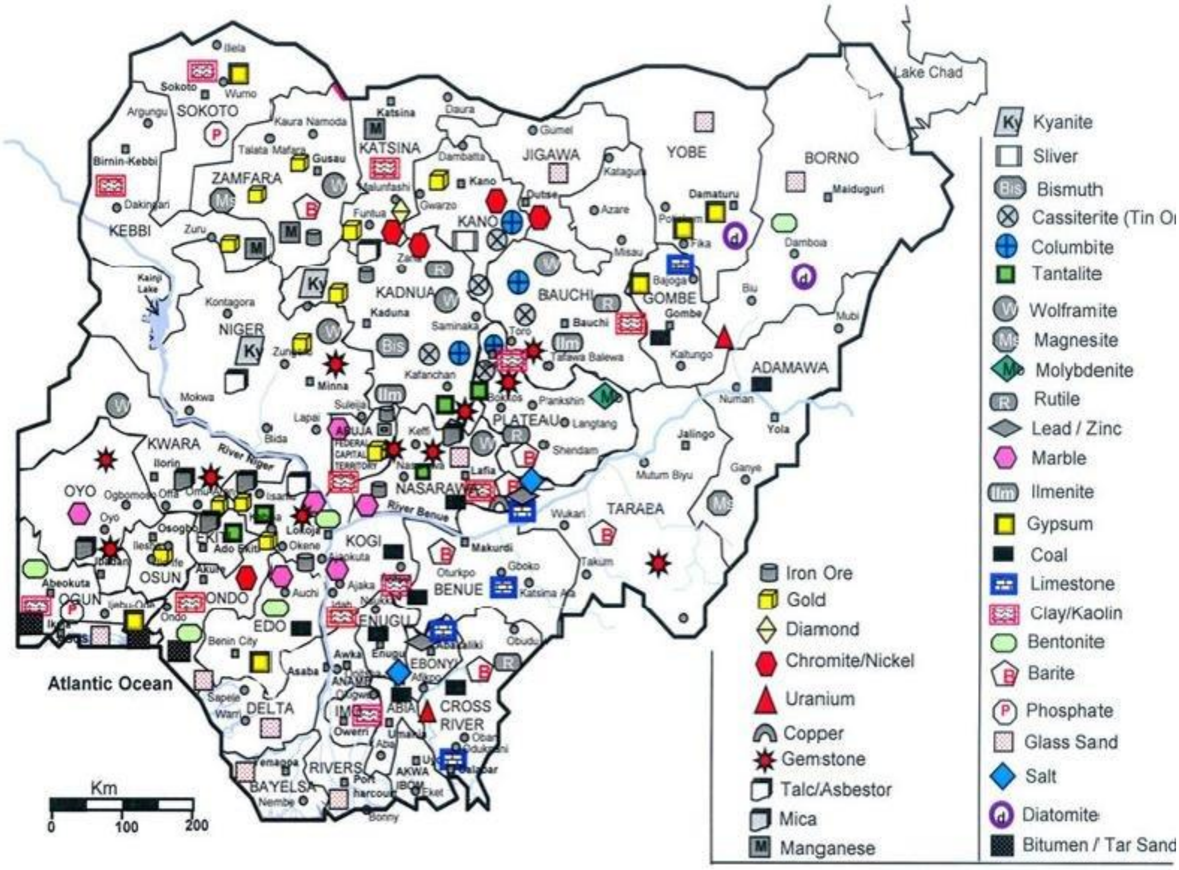

figure (1) Geological map of the study area (NGSA, 2006)

data acquisition :

Four High Resolution Aeromagnetic data of Gandi (sheet 30), kauran Namoda (sheet 31), Anka (sheet 52) and Maru (sheet 53), which lies from the 12°N to 13°N and longitude 5.5°E to 6.5°E,This data which covers the entire study area were purchased from Nigerian Geologic Survey Agency, which are on a scale of 1:100,000.This data was acquired at a flight altitude of 80 m, along NE-SW flight lines spaced approximately 500 m apart.

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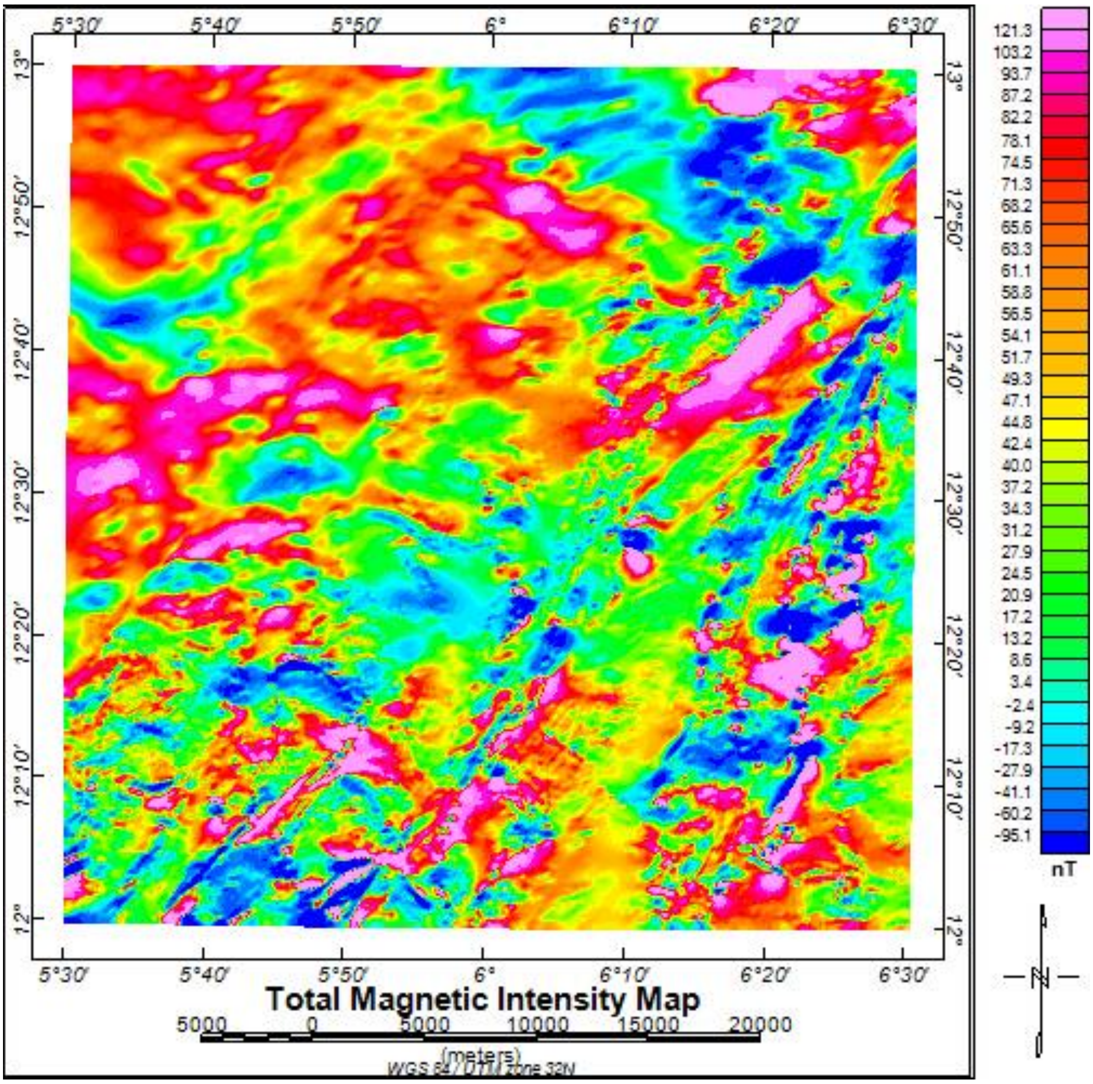

Figure; (2) the magnetic intensity of the study area

Materials and Methods

High Resolution Aeromagnetic (HRAM) data of Gandi (sheet 30), Kauran namoda (sheet 31), Anka (sheet 52) and Maru (sheet 53),which covers the area under consideration, the data was obtained from the Nigerian Geologic Survey Agency (NGSA).The residual anomaly was separated from the regional magnetic field by using the polynomial fitting method for all the values in the grid. The regional magnetic field contour map of the study area shows a NE-SW trend in orientation of deeper magnetic sources with an increase in magnetization from NW to SE of the area. The residual anomaly data was interpolated using a minimum curvature gridding algorithm, available in the Geosoft Oasis Montaj6.4.2 software, with a grid cell size of 250 m. The resulting residual magnetic anomaly map is presented in Figure 3.Areas with high magnetic minerals (pink colored) can be clearly distinguished from areas with low magnetic minerals (blue colored) in the map (Figure 3). The NNE-SSW trend in high magnetic content is suggestive of the presence of high magnetic minerals within the Maru Schist Belt. Various filtering techniques were applied on the residual magnetic field grid in order to aid interpretation. These filtering techniques were selected because they best delineate to support the research interest of the work. The techniques include; the enhancement order derivative, analytic signal, the Tilt derivative, Source parameter image (SPI) and the Euler De convolution techniques. The theories of these techniques are briefly discussed below.

First vertical derivative 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

)

where ∇^2f is the Laplace transform which can be expressed in full as:

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

(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:

$$\mathrm{F}\left[\frac{\partial^n f}{\partial z^n}\right] =$$

$$k^n \mathrm{F}(f)$$

The second vertical derivative has more resolving power than the first vertical derivative. Apart from enhancing the shallow anomalies, the second vertical derivatives are also used to delineate geological boundaries between rocks with contrasting physical properties such as magnetic susceptibility. The contoured second vertical derivative outlines the bodies causing the magnetic anomalies (Labbo & Ugodulunwa, 2007). The second vertical derivative is based on equation 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.

Analytic signal

The analytic signal or total gradient is formed through the combination of the horizontal and vertical gradients of the magnetic anomaly (Ansari & Alamder, 2009) in Thabisani et al., (2015). Its form over a causative body depends on the location of the body (horizontal coordinate and depth) but not its magnetization direction (Thabisani et al., 2015). 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. The filters ability to generate a maximum value directly over the causative body and depth estimation makes it a highly useful technique for magnetic data interpretation (Ansari & Alamdar, 2009) and Thabisani et al., (2015).One advantage of the Analytic Signal technique is that it defines source positions regardless of any remenant magnetization in the sources hence it's independent of the direction of magnetization

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

(1

$$A(x,y) = \left(\frac{\partial M}{\partial X}\right) X + \left(\frac{\partial M}{\partial Y}\right) Y + \left(\frac{\partial M}{\partial Z}\right) Z \qquad (4)$$

With M= magnetic field. The analytical signal Amplitude can now be written as:

$$|A(x,y)| = \sqrt{\left(\frac{\partial M}{\partial X}\right)^2 + \left(\frac{\partial M}{\partial Y}\right)^2 + \left(\frac{\partial M}{\partial Z}\right)^2} (5)$$

(3)

Tilt Derivative:

The tilt derivative filter is defined as

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

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

VDR= $\frac{\partial T}{\partial z}$ and RHDR= $\sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2}$(7)

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:

Hence, THDR−TDR= $\sqrt{\left(\frac{\partial TDR}{\partial x}\right)^2 + \left(\frac{\partial TDR}{\partial y}\right)^2}$ (8)

Source Parameter Imaging (SPI);

Thurston & Smith (1997) developed source parameter imaging and used it to estimate the depth from the local wave number of the analytical signal. The depth is displayed as an image which makes it better than other depth estimation methods. One more advantage of the source parameter imaging technique is that the estimation of depth is independent of the magnetic inclination, declination, dip, strike and any remnant magnetization (Thurston & Smith, 1997). Hence the technique has been used for depth estimation of magnetic sources by many authors. Salako (2014),Marwan et al., (2017) and Nwogwugwu et al., (2017) applied it for depth to basement determination. Solution grids using the Source Parameter Imaging technique show the edge location, depth, dips andSusceptibility contrasts.

Thurston and Smith (1997) estimated the depth parameter using the local wave number of the analytic signal. The analytical signal $A_1(X, Z)$ is defined by Nabighian, (1972) as

$$A1(x,z) = \frac{\partial M(X,Z)}{\partial x} - j\frac{\partial M(X,Z)}{\partial z}$$

where $A_1(x, z)$= Amplitude of Analytical signal

M (x, z) = magnitude of the anomalous total magnetic field
j = imaginary number
z and x= are gradients in the vertical and horizontal direction respectively.

Nabighian (1972) also showed that the gradient changes constituting the vertical and horizontal (real and imaginary) parts of the 2D analytical signal are related as follows:

$$\frac{\partial M(X,Z)}{\partial x} \Leftrightarrow -j\frac{\partial M(X,Z)}{\partial z}$$

Where ⇔ represents a Hilbert transform

The local wave number $k_1$is defined by Thurston & Smith (1972) to be

$$k_1 = \frac{\partial}{\partial x} tan^{-1}\left[\frac{\partial M}{\partial z} \middle/ \frac{\partial M}{\partial x}\right] (11)$$

According to Salako & Nwosu (2014) the signature illustrated by Thurston and Smith (1972) utilized Hilbert transformation pair in (3.11). The Hilbert transform and vertical derivative operators are linear, so the vertical derivative of (11) will give the Hilbert transform pair as

$$\frac{\partial^2 M(X,Z)}{\partial z \partial x} \Leftrightarrow -\frac{\partial^2 M(X,Z)}{\partial^2 z}$$

Thus the analytic signal could be defined based on second order derivative $A_2(x, z)$

Where

$$A_2(x,z) = \frac{\partial^2 M(X,Z)}{\partial z \partial x} - j\frac{\partial^2 M(X,Z)}{\partial^2 z}$$

This gives rise to a second order local wave number k_2, where

(9)

$$k_2 = \frac{\partial}{\partial x} \tan^{-1}\left[\frac{\partial^2 M}{\partial^2 z} \middle/ \frac{\partial^2 M}{\partial z\, \partial x}\right] (14)$$

The first and second order local wave numbers are used to determine the most appropriate model and depth estimate independent of any assumption about a model.

Euler De convolution

The Euler De Convolutions a 3-Dimensional semi-automatic interpretation technique widely used in depth estimation and delimitation of a wide variety of geologic structures. It is based on Euler homogeneity equation (3) 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

(10)

$$(x\text{-}y) = \frac{\partial T}{\partial x} + (y - y)\frac{\partial T}{\partial y} + (z - z)\frac{\partial T}{\partial z} = N\ (B\text{-}T)$$

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 unknown x_o, y_o, z_o 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 and Reid suggested that a correct N gives the tightest clustering ofthe Euler solutions around the geologic structure of interest. Thompson gives more detailed discussion on the degree of homogeneity of potential fields and structural indices of Euler De Convolution.

(12)

II. RESULTS AND DISCUSSION

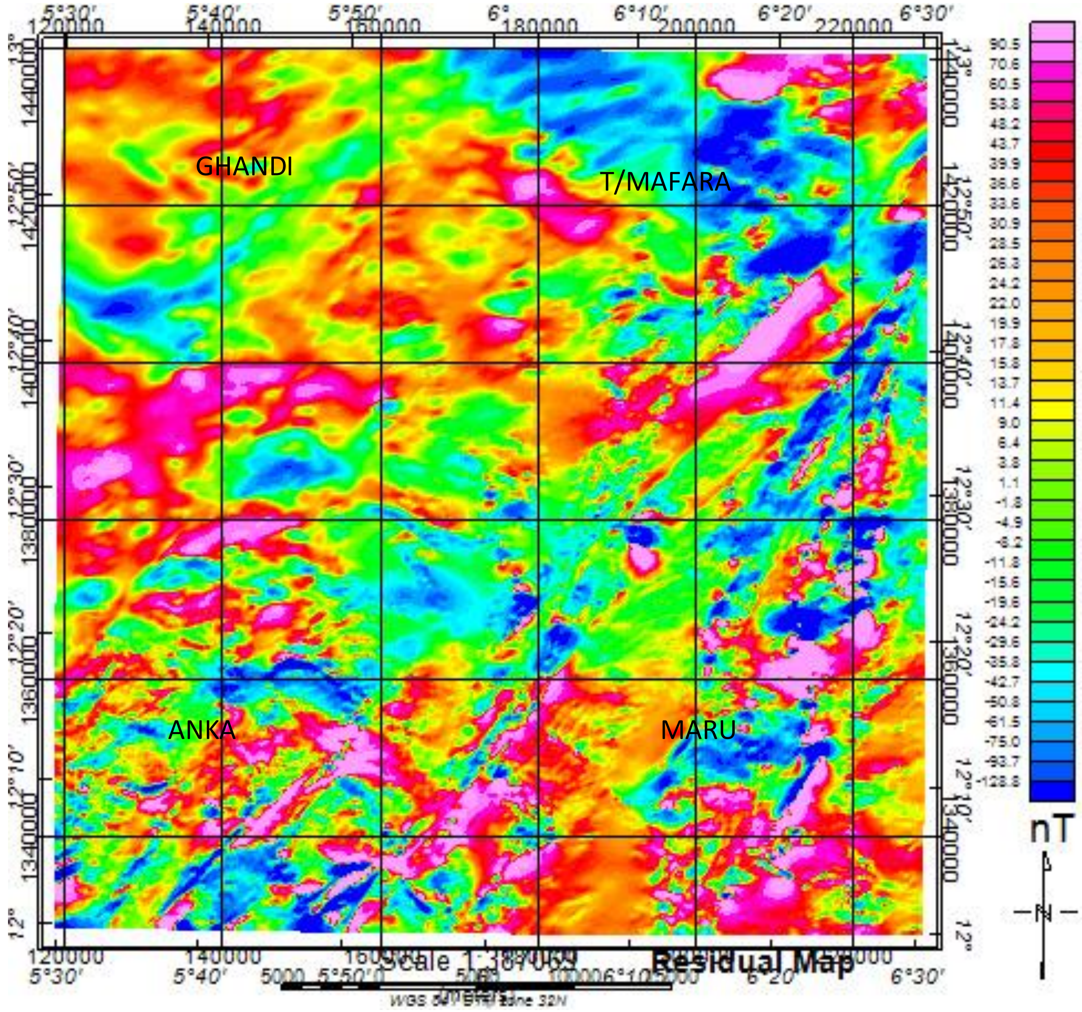

Figure (3) the residual map of the study area

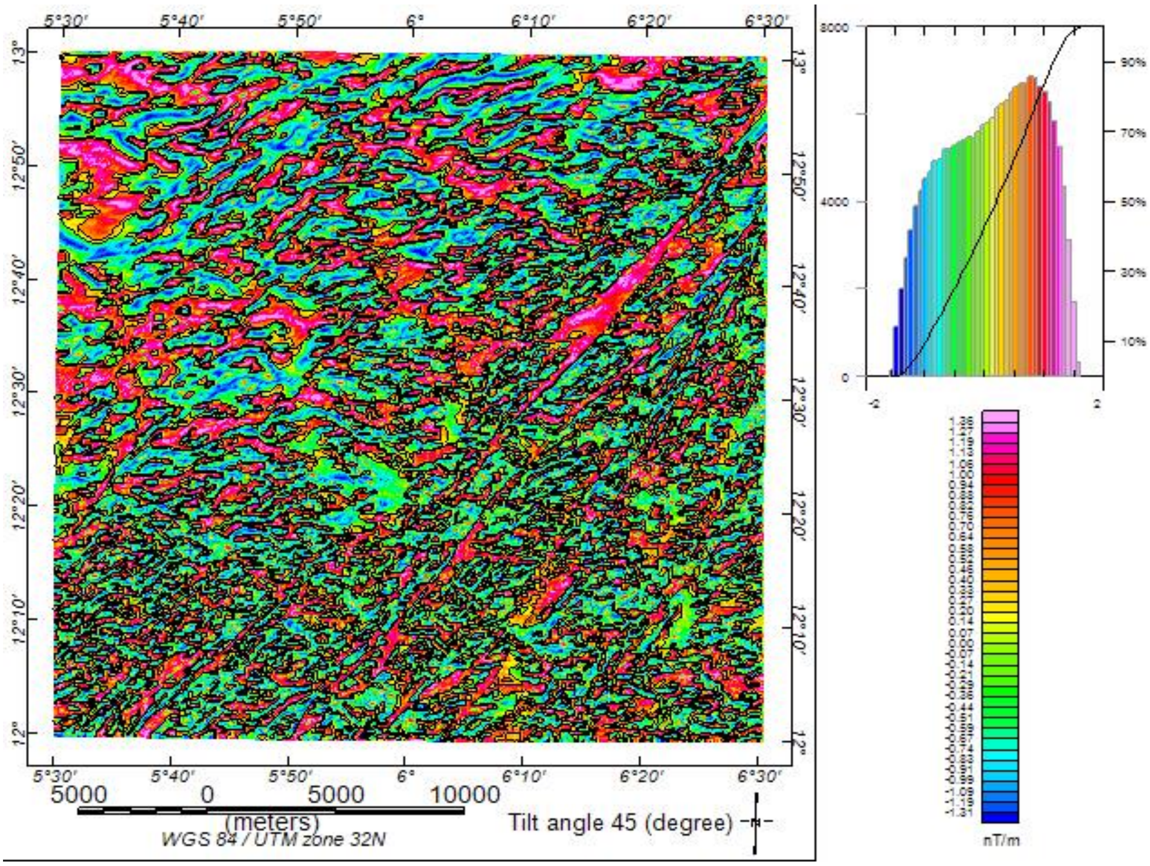

Figure (4) the tilt derivative map of the study area

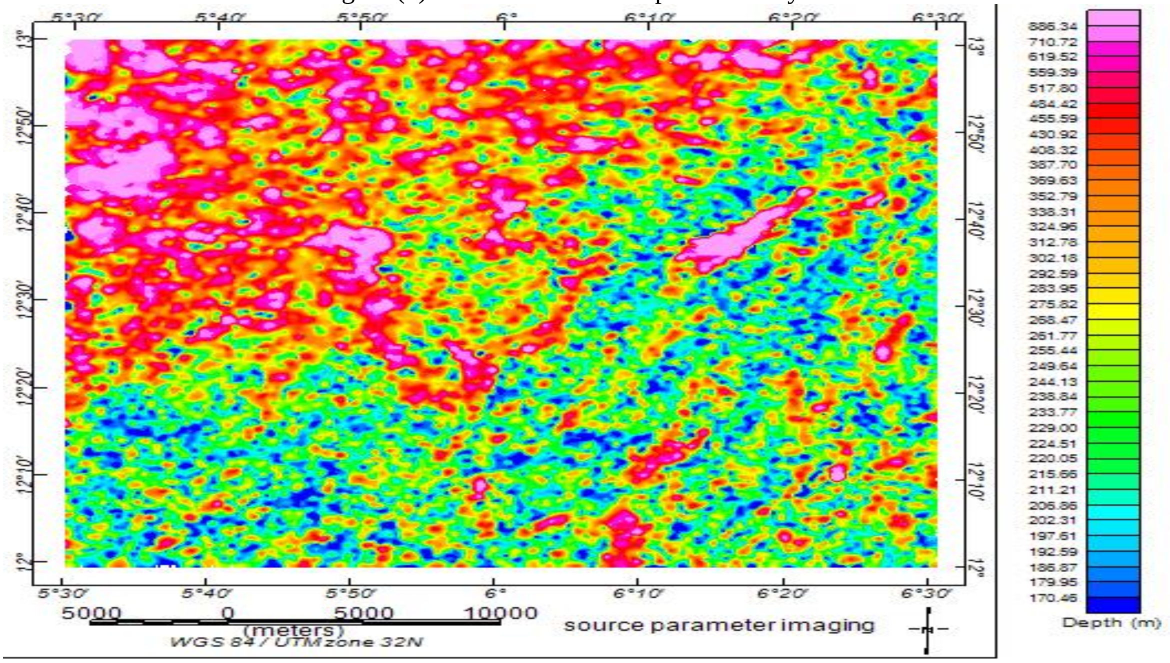

Figure (5) the source parameter image map of the study area

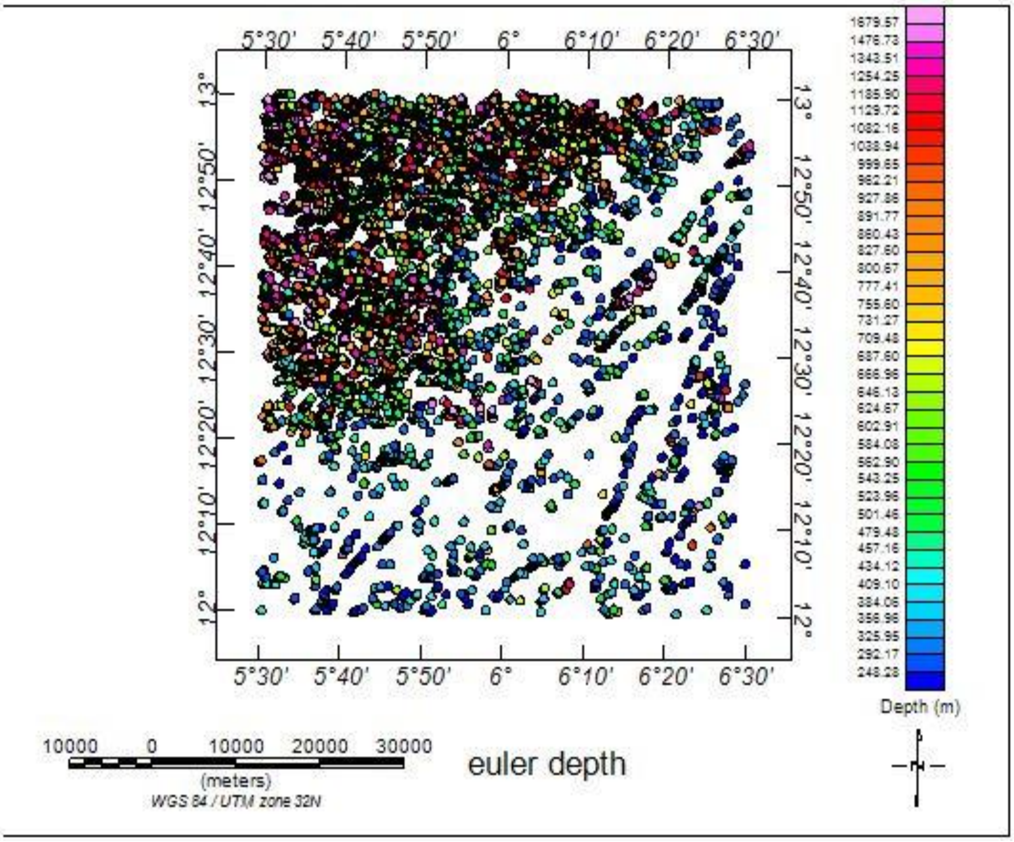

Figure (6)Euler depth map

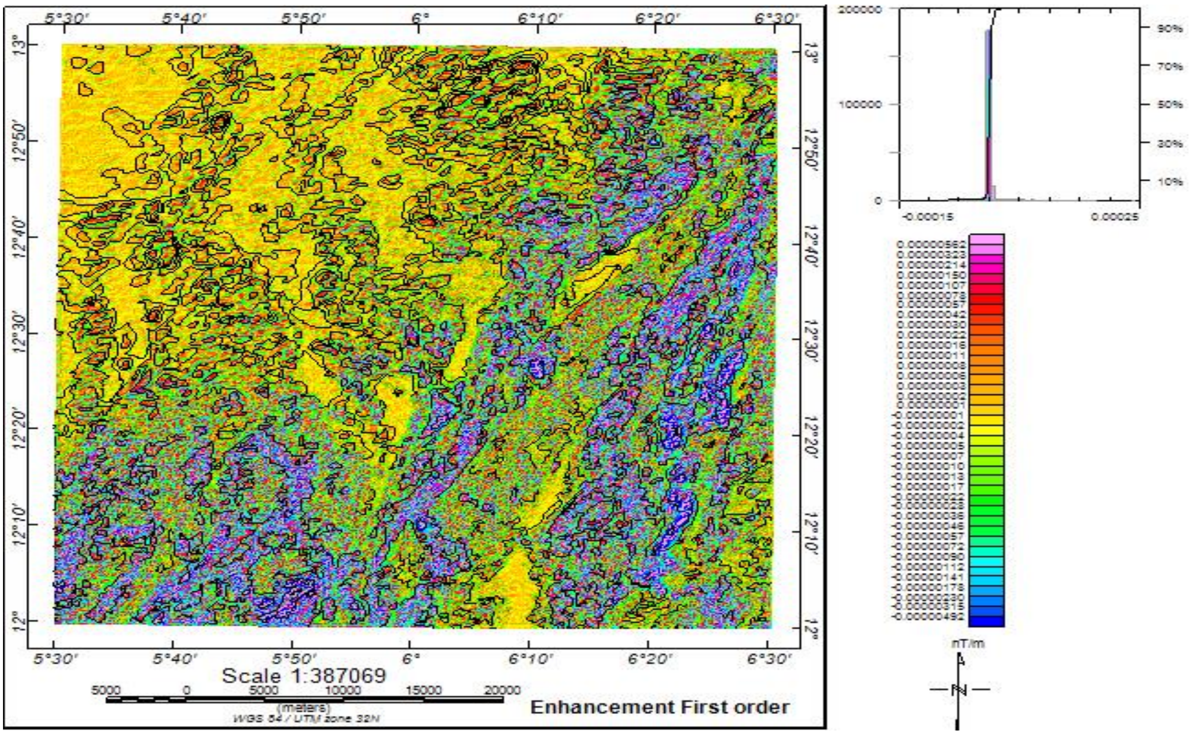

Figure (7) enhancement first order

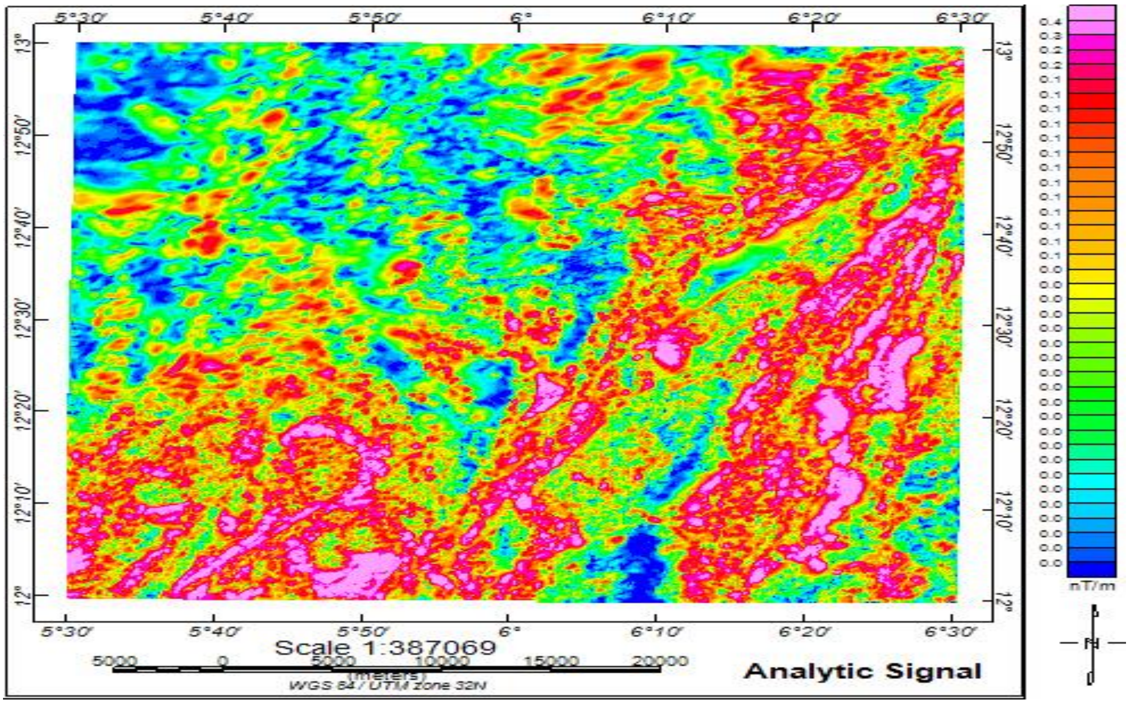

Figure (8)Analytic signal map

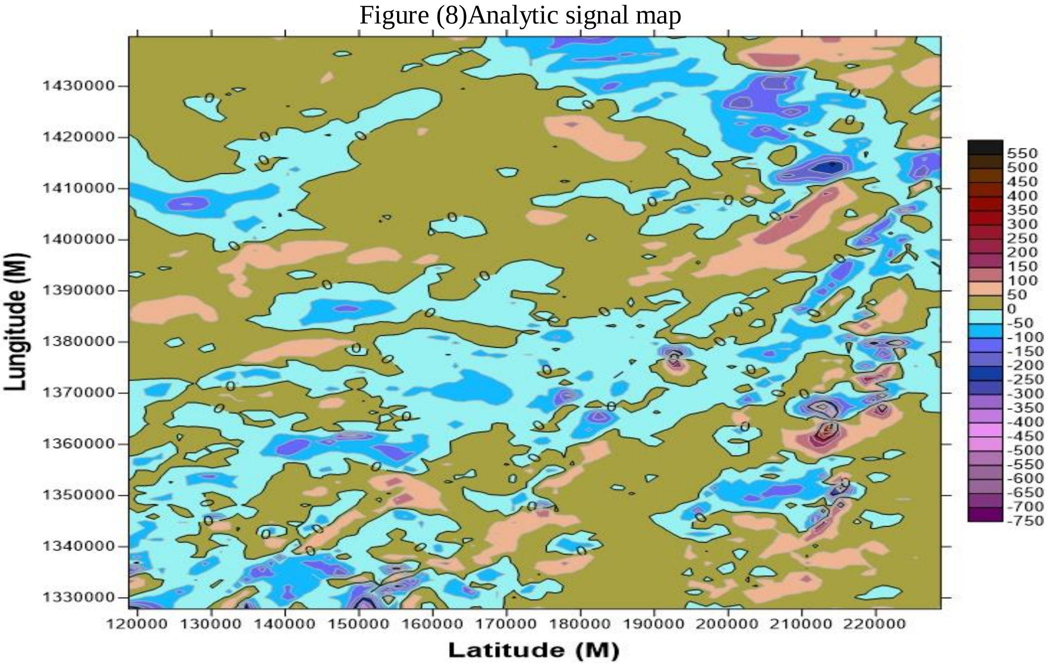

Figure (9) contour map of the study area

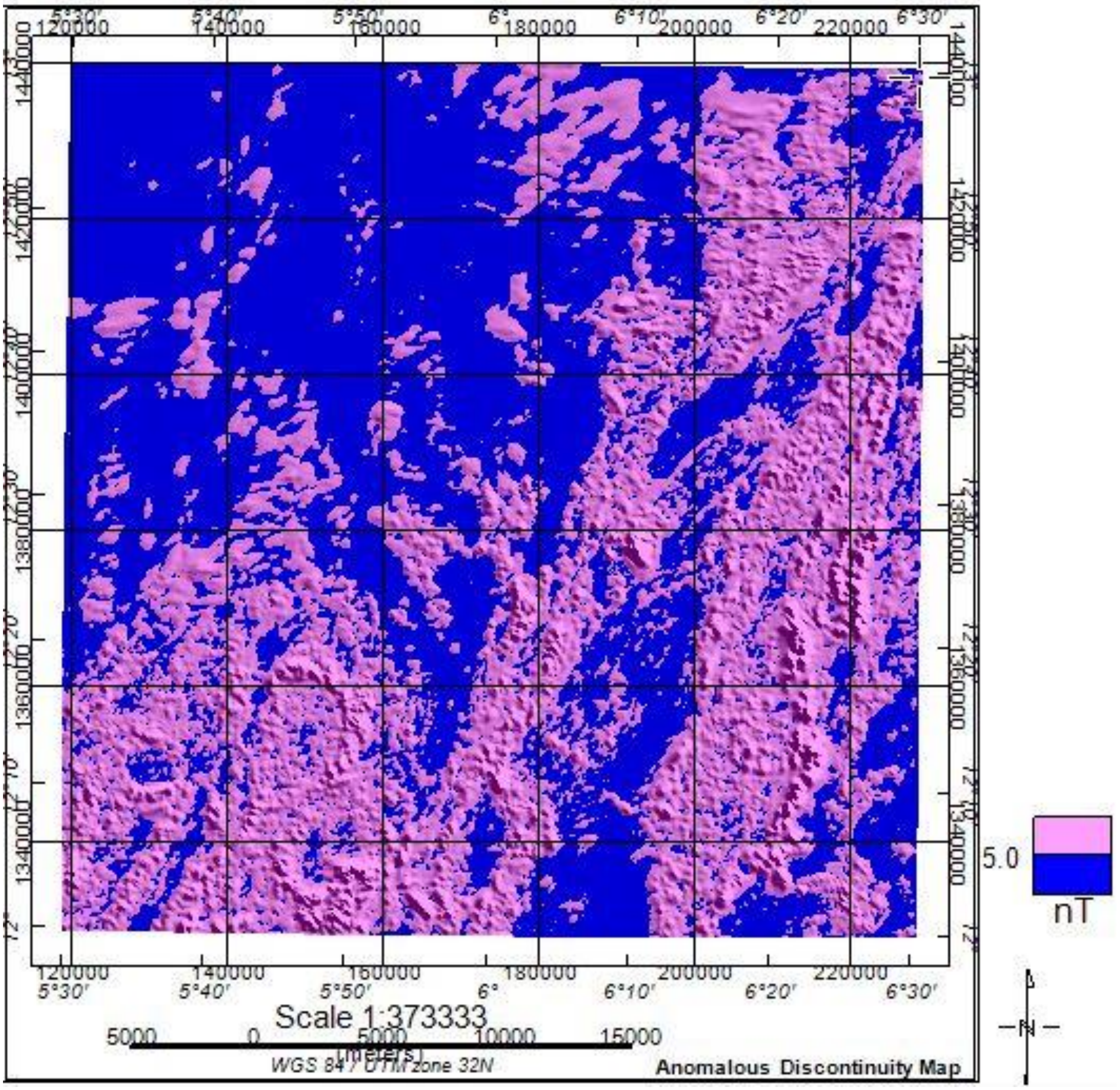

Figure (10) anomalous discontinuity map

Regional and residual separation of magnetic anomalies

Magnetic data interpretation usually commences with some procedure that separates the smooth, presumable deep-seated regional effects from the observed field so as to obtain the residual effects, which are the anomalies of geological interest (Figure 2). The regional magnetic fields are large features which generally show up as trends and continue smoothly over very considerable areas, and they are caused by deeper homogeneity of the earth's crust. Theophile et al,(2012) The regional magnetic field contour map is shown in Figure (8)the magnetic field intensity values in Figure 1 show the trend from EW-SW direction, the residual magnetic intensity map is illustrated in Figure (2), this was done using SURFER 12 and Oasis Montaj software.

Data enhancement

First vertical derivatives were used in this research to enhance the field data, the first vertical derivative map is shown in Figure (6) which shows the response of the target structures. This helps remove noise caused by high frequency shallow anomaly. Anomalous map of the study area is shown in Figure(9).

III. RESULTS AND INTERPRETATION

Analytic Signal filtering technique, applied on the residual magnetic field data, is presented in Figure (4). The Analytic Signal (AS) filter helps to detect sources position irrespective of direction and remnant magnetization Roest WR et al.,(1992) It displays maximum amplitude directly over the edge of the magnetic source hence it is used to locate boundaries of magnetic bodies responsible for the anomalies.

On Figure (7) areas with variable magnetic contrast were delineated with the amplitude of analytic signal varying from 0.0 to 0.4nT/m. High amplitude analytic signal values observed can the attributed to the ferrous minerals present in the study area. Peak values

are observed in Anka down to the, Maru and some part of the Talatan mafara in the study area. With this can be observed that areas with low AS are underlain mostly by granitoids rocks.

Euler De convolution technique

The Euler De Convolution algorithm was implemented to the gridded residual field intensity map (Figure 5) in order to obtain depth to magnetic sources. This was done in order to obtain well-informed depth information of magnetic materials within the area of study. For both models, a window size of 10 and maximum depth tolerance of 10 % were assumed. From the two maps, the depths to magnetic source within the area are predominantly below 300 m, especially area with suspected faults. However few areas with depths above 600 m are distinguished within the area.

Source Parameter Imaging (SPI)

Source parameter imaging highlights spatial location of different magnetic sources at various depths. The result of the source parameter imaging of aeromagnetic data generated from the residual data of the study area (Figure 4) revealed maximum depth of 886.34moccurring majorly at the northeastern part of the study area which correspond to Gandi and some part Anka. Minimum depth of 170.46 m occurred at the western, and southwestern part of the area which corresponds to maru and Talatan mafara. The basement depth obtained in this research agreed well with the result of the published research conducted by Adetona et al.,(2007). The traces of white portion of the SPI grid map are the areas where the structural index cannot be reliably estimated due to small local wave number. The model independent local wave number had been set to zero in those areas.

CONCLUSION

The results of this work have revealed that the rock types and geological units of the study areas are Gudumi formation (sandstones and alluvial), metasediments (quartzite, phyllite and metaconglomerate) and the basin granitoids (fine and coarse grain granites) which intruded were clearly mapped. From the NS through the central parts of the study area associated with sandstone and alluvial. The study area mainly associated with metasediments with pockets of weathered regolith and felsic sediment Also meta sedimentary and sedimentary rock types, is very rich in iron mineralization from the map. The study area also shows the presence of hydrothermally altered iron mineralization (ferric and ferrous) distributed at various degree round the study area. The Analytical map and the euler map correlated positively with the iron mineralization map .The depths to various geological structural model (Dikes, contacts, faults. Also the result revealed the maximum depth of 886.34m of the study area occurring majorly at the northeastern part of the study area which correspond to Gandi and some part Anka. And Minimum depth of 170.46 m occurred at the western, and southwestern part of the area which corresponds to Maru and Talatan mafara.

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