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Delineation of Structural Featuresand Depth to the Magnetic Sources over Allawa and its Environs, Northcentral Nigeria.

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ABSTRACTS: High resolution aeromagnetic data of Allawa and its environs was first reduced to the magnetic pole (RTP) to place the magnetic anomalies directly above their respective causative sources. The residual magnetic intensity (RMI) derived from RTP was subjected to the shallow enhancement filters involving; first vertical derivatives (FVDR) and horizontal gradient magnitude (HGM). The FVDR and HGM methods delineated series of linear geologic features which could be interpreted as faults, folds and fractures.The centre for exploration targeting (CET) in conjunction with constructed Rose diagram revealed that the study region is dissected by series of major and minor deformations trending along the NE–SW, N-S, E-W and NW-SE directions respectively. Afterwards, analytic method was also utilised to estimate the depth to the magnetic sources with resulting values in the range of 108.4 to 322.4 m. Therefore, the adopted methodshave aided in unveiling the depths and pathways controlling the mineralisation over the region.

Keywords: First vertical derivatives, Reduced to pole, Horizontal Gradient magnitude, Lineaments and Analytic signal depth estimate

I. INTRODUCTION

Over the years, high resolution aeromagnetic dataset has been adopted globally in the both minerals and hydrocarbons prospecting. The magnetic survey method receives much attention because it is relatively cheap and fast in both rough and smooth terrain [1]. The magnetic method measures the variation in the earth magnetic field which is produced due to the remnant and induced magnetization between the mineralized bodies and the host rock [2]. The detection of structural features and depths to the magnetic sources has been reported in some part of the Nigeria. For example, [3]. Determined the positions and depths to the iron ore deposits of Okene Northcentral Nigeria from magnetic dataset.[1]. Estimated the depths and locations to the magnetic source anomalies within the Danko area of Kebbi state.[4]. Interpreted aeromagnetic data with the sole purpose of obtaining the average sedimentary thickness and structural pattern over Mutum-Biyu and environs, in Taraba northeast Nigeria.However,the present study area (Allawa) and its environs falls within the basement complex of Nigeria which is underlain by numerous faults, fractures and shear zones which perhab serves as pathways for several mineral deposits[5].These region has not been capturedfor any geophysically study and has over a decade acts as host for artisanal mining activities.It is quite alarming that these artisanal miners have little mining expertise because they ventured into trial and errorpit excavations. These perhapshave caused severe devastating environmental and radiological effects including; destruction of natural flora and fauna, landscape degradation, flooding, erosion, air and water toxic pollutions [6].

It is worth mentioning, that the study area falls within the low latitude region. At this region, local magnetic anomalies usually have smaller magnitude in comparison to those produced by similar structures at higher latitude [7].However, reduction to the magnetic pole (RTP) placed the magnetic anomalies directly over their respective causative sources as reported by [8]. [9]. [10].In order to mitigate the devastating environmental and radiological health risks, the present study mainly focus on the delineation of the subsurface geologic features in the identification of the structurally controlled mineralised zones and also estimate the depths to the magnetic sources anomalies. Therefore, first vertical derivative (FVDR), Horizontal gradient magnitude (HGM) and Centre for Exploration Targeting (CET) methods are utilised for the structural delineation and the depth to the magnetic sources are inferred using the analytic signal depth method.

II. GEOLOGICAL SETTING OF THE STUDY AREA

The study area is bounded by latitudes 10°15′00″N to 10°45′00″N and longitudes 6°30′00″E to 6°45′00″E. The area under study (Allawa and its environs) falls within the Basement Complex Nigeria. [11].Regionally categorised the Basement Complex of Nigeria into four (4) major lithological units namely; the Migmatites-Gneiss Complex, Schist belt (Metasedimentary and Metavolcanics rocks), Older Granites (Pan African Granitoids) and Undeformed Acid and Basic Dykes (Fig.1).The Basement Complex of Nigeria are presumed to be formed from the resulting four major orogenic sequences of deformation, metamorphism and remobilization which corresponds to the Liberian (2,700 Ma), Eburnean (2,000 Ma), Kibaran (1,100 Ma) and the Pan-African (600 Ma). The first three sequences are defined by intensive deformation and isoclinal folding conveyed by regional metamorphism which was later accompanied by extensive migmatization [11].Whereas, the production of the syntectonic granites and homogeneous gneisses of the Pan African deformation was accompanied by a regional, migmatization, metamorphism and extensive gneissification and granitization [12]. Therefore, the major lithological units (Fig.2) occupying the current study area includes; Migmatites, Migmatites-Gneiss, MigmaticAugen Gneiss, Biotite Hornblende Gneiss, Pelitic schists and Muscovite schistsand lastly, Undifferentiated schists including phyllites.

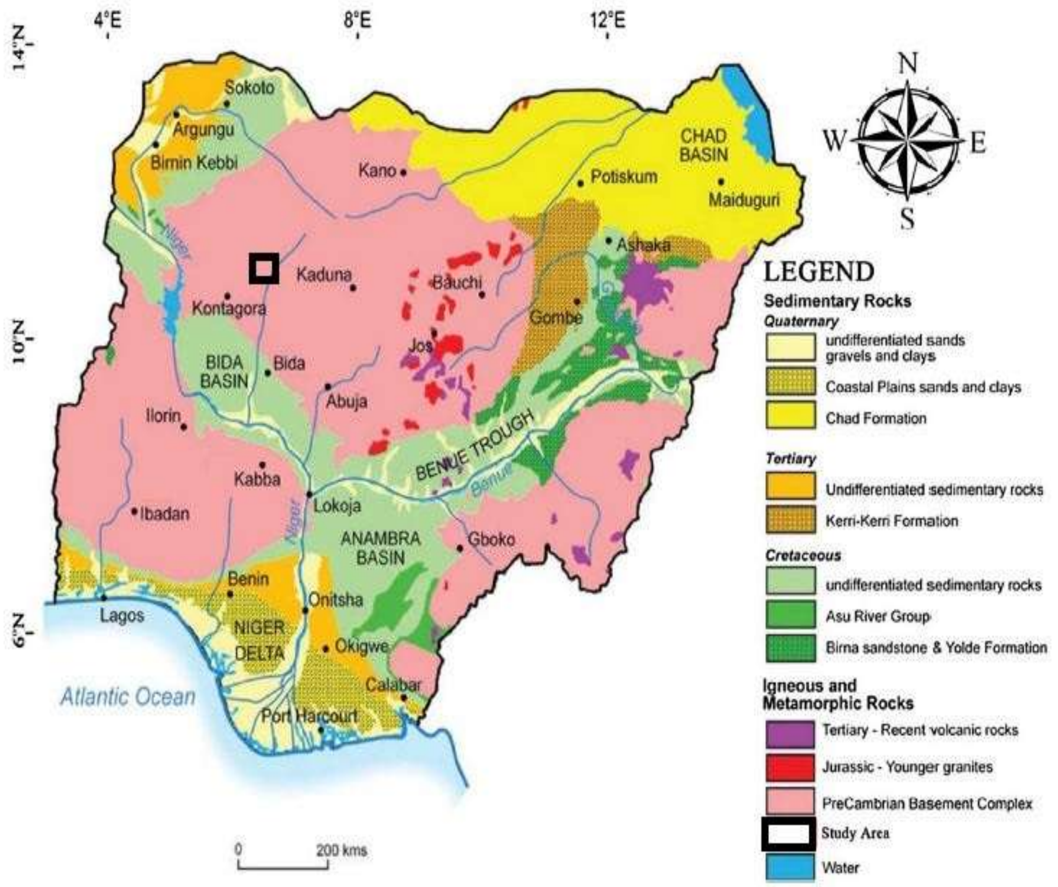

Fig. 1 Geological map of Nigeria showing the study area modified after [13].

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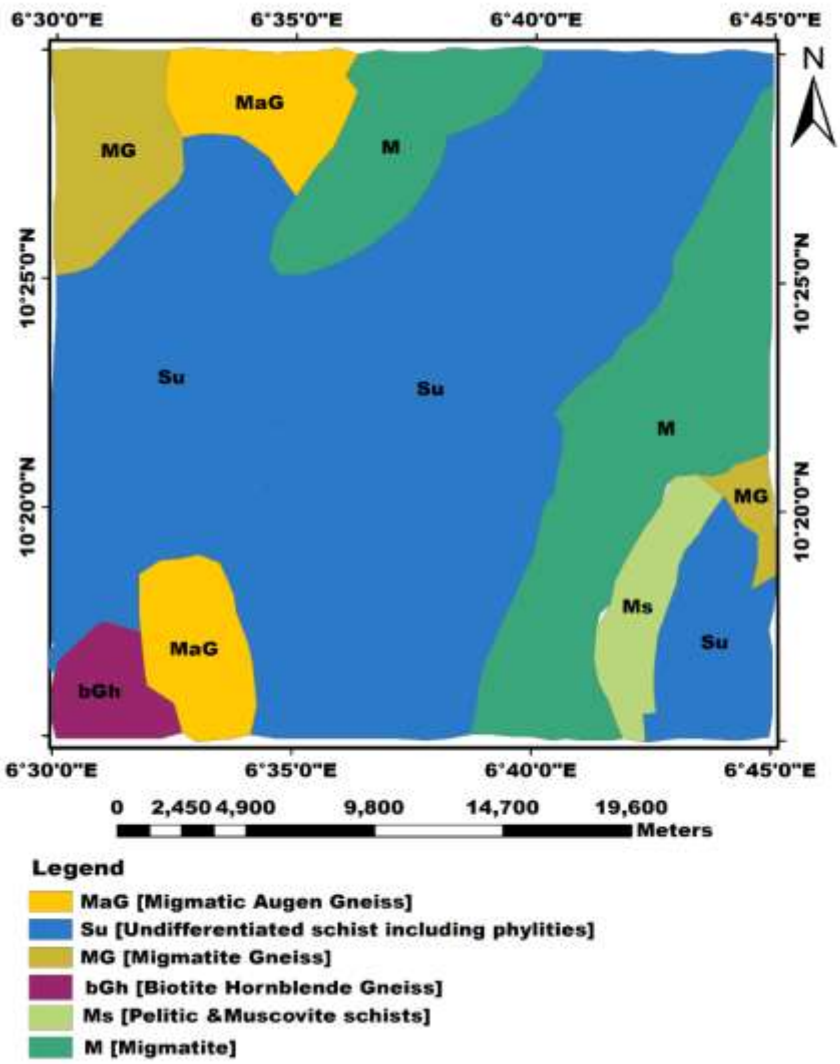

Fig. 2 Geological map of the study area modified after [14].

III. MATERIALS AND METHODS

Data Acquisition

The Nigeria Geological Survey Agency (NGSA) carried out geophysical survey covering all part of Nigeria. The magnetic datasets were acquired through an attached 3×3 Scintrex CS3 cesium vapour magnetometer sensor on a fixed wing of the aircraft. The aircraft was flown along the NW-SE directions, with a line spacing of 500 m, mean sensor terrain clearance of 80 m and tie lines of 2000 m interval. The acquired data were corrected for both the Diurnal variation and the International Geomagnetic Reference Field (IGRF). The corrected aeromagnetic dataset was subjected to the Bi-directional gridding method to produce the Total magnetic intensity (TMI) anomaly grid shown in the Figure 3a. The TMI anomaly data was reduced to magnetic pole. The inclination, declination and magnetic field intensity values of -5.579^0 and -0.582^{0}were respectively used as the required parameters for the RTP correction.

Methods

Detection of structural features

First vertical derivative (FVDR)

The first vertical derivative (FVDR) is a high pass filter that is applied to the RTP of the potential field magnetic dataset to calculate its gradient vertically. The FVDR sharpens the effect of high frequency (short wavelength) magnetic features. It is also useful for enhancing the textural variation in the data.

$$L(r) = r^n$$

where, n is the order of differentiation.

Horizontal Gradient Magnitude (HGM)

The Horizontal Gradient Magnitude (HGM) locate subsurface geologic features such as;

contact zones, fractures and faults from potential field dataset, where the HGM map produce a maximum ridge over the edges of contacts or faults. The HGM method only used the two first-order horizontal derivatives of the magnetic field, which makes it low sensitive to the noise in the magnetic data [15]. If T (x, y) is the total magnetic intensity field at location (x, y), the HGM is given as thus:

$$HGM(x, y) = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2} \quad (2)$$

where, the horizontal derivatives are $\frac{\partial T}{\partial x}$ and $\frac{\partial T}{\partial y}$, of the aeromagnetic data.

Centre for Exploration Targeting Grid Analysis.

[16].Revealed that the Centre for Exploration Targeting (CET) detects linear geologic features and structural complexity from a potential field data. These method is applied based on the following procedures which includes; the textural analysis which involves the calculating the standard deviation in order to determine the magnetic discontinuities and complex textures zones. Next, the generated standard deviation grid was subjected to the lineation and vectorisation grid to produce the structural complexity map of the study area.

ESTIMATION OF DEPTHS TO MAGNETIC BASEMENTS

3D Analytic Signal (As)

The AS is an essential technique used in detecting the boundaries of high and low magnetic features close to the magnetic equator [17].The AS techniquealso centres the peaks of the magnetic source anomalies over their respective causative sources at bothand high and low latitude regions [7].Thetechnique is independent of the direction of magnetisation and it is slightly affected by noise [18].The AS technique is defined as the square root of the sum of the vertical and horizontal derivatives of magnetic field given as thus:

$$A(x, y) = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2} \quad (3)$$

where, the first derivatives $\frac{\partial T}{\partial x}, \frac{\partial T}{\partial y}$ and $\frac{\partial T}{\partial z}$ of the total magnetic field and x, y and z are the directions [19].More so, the AS technique is capable of estimating the depths to the magnetic sources over the study area, which perhab can be attributed to mineral deposits. The depths estimate depends on the source geometry known as structural index (SI) of the anomaly of interest [20]. The depths to the magnetic sources are estimated under the assumptions that the anomalies are in two dimension (2-D). Hence, the depths to the magnetic source anomalies are estimated as given in the equation below:

$$AS1 = \sqrt{\left(\frac{\partial fv}{\partial x}\right)^2 + \left(\frac{\partial fv}{\partial y}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2} \quad (4)$$

On the maximum amplitude

$$D = \frac{AS}{AS1} * N \quad (5)$$

where,
fv = First vertical derivative of the residual map,
D = Depth to the magnetic sources,
AS = Analytic signal of the residual grid,
AS1= Analytic signal of first vertical derivative of the residual grid.
N = 1 (contact), N = 2 (dike), N = 3 (pipe), and N = 4 (sphere) [20].

IV. RESULTS AND DISCUSSIONS

The total magnetic intensity (TMI) anomaly map depicted (fig.3a) has intensities in the range of 2.13 to 60.06 nT. Segments covered by high (strong) magnetic signatures are portrayed in (pink to red colours) which are predominantly found in northern, eastern especially in the south-eastern corner of the study area, whereas from the mid portion to western and some portions of the southern parts of the study area are dominated by average to weak magnetic signatures in (green to blue colours). In particular, visual inspection of the trends from the TMI are in NE-SW and E-W directions. Since, the area under study falls within the low region i.e. close to the magnetic equator. At these region, there is reversal in the magnetic signatures caused as a results of the distortions in the direction of magnetisation (inclination and declination) of the magnetised bodies. However, in an attempt to overcome the misrepresentation of the magnetic anomalies at the low latitudes region, the TMI grid was subjected to the RTP filter. The RTP eliminate the distortions (asymmetric and lateral shift) of the magnetic anomalies due to the magnetisation direction from the north [21].

The produced reduce to the pole map (fig.3b) has magnetic intensities in the range of 1.53 to 60.34 nT. However, RTP map has clearly repositioned the magnetic signatures in comparison to the total magnetic intensity map (fig.3a) i.e. Segments overlain by low magnetic signatures on the TMI are actually the segments covered by high magnetic signatures on the RTP map and vice versa. The strong magnetic signatures in (pink to red colours) diagonally cuts across the Northeastern (NE) to Southwestern (SW) of the study area. These high magnetic signatures are due to the metavolcanics rocks whereas the low magnetic signatures in (green to blue colours) are due to metasediments rocks predominantly found in the western (W) and North Northwest (NNW) to mid portion of the study area.

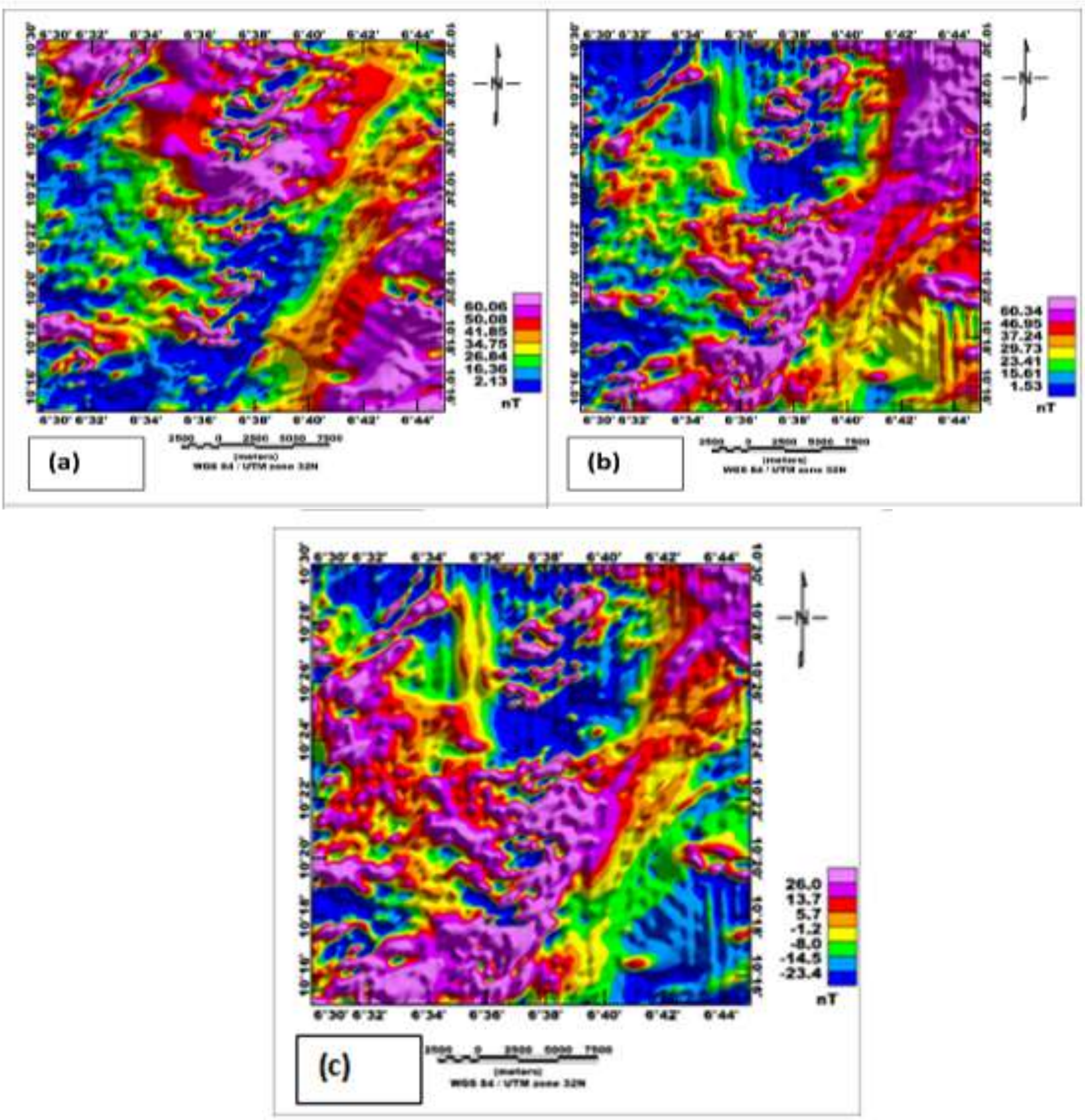

Fig. 3: (a) Shaded colour TMI map; **(b)** shaded colour RTP map and (**c)** shaded colour RMI map

The shaded colour residual magnetic intensity map (fig.3c) represents the shallow seated magnetic signatures that are overshadowed by the deep seated (regional) magnetic signatures over the study area. The RMI map is characterised by both high positive and negative magnetic signatures with intensities in the range of and -23.4 to 26.0 nT of different amplitudes and magnitudes. However, the RMI had similar trend of magnetic anomalies signatures when compared with the RTP map (fig.3b). Additionally, there is attenuation in the magnetic anomaly signatures observed at the SE corner of the study area in comparison to the RTP map (fig.3b). The (pink to red colours) signifies the segments of high positive magnetic signatures which are perhaps be due to magnetite rich rocks and massive pyrrhotite of remnant magnetisation origin [22]. The (green to blue colours) denotes segments with moderate to high negative magnetic signatures which could be associated to the

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alteration processes destroying the pyrrhotite contents [22].

V. DISCUSSIONS ON THE EDGE DETECTION

First Vertical Derivative (FVDR) Map

The first vertical derivative map (fig.4a.) has succeeded in depicting geologic features with long wavelength while enhancing the short wavelength magnetic features. The resulting first vertical derivative map is compared with the residual magnetic intensity map (Fig.3c) and increment in the visibility of the structural features were observed. The (yellow to blue colours)with magnetic intensities in the range of (-0.00 to -0.05 nT/m) represent the segments with somewhat thicker metasediments formations.While the (green to pink colours) with magnetic intensities in the range of (0.01 to 0.05 nT/m) denotes the segments overlain by shallow magnetic materials which of metavolcanics origin.However, the FVDR grid was further subjected to Centre for exploration targeting and series of linear geologic features (such as such faults, fractures and folds) were observed as shown in figure 5a. In order to determine the trends of the delineated geologic features from the FVDR map, a rose diagram (fig.6a) was constructed and both major and minor trends were delineated in the NE-SW, N-S, E-W andNW-SE directions respectively.

Horizontal Gradient Magnitude (HGM) map

The residual magnetic intensity (RMI) was subjected to the Horizontal Gradient Magnitude (HGM) filter as depicted in (Fig. 4b). The HGM techniquecreated maxima linear features over the edges of magnetic contacts.The (green to blue colours) signifies segments with weak magnetic intensities with values in the range of(0.01 to 0.03 nT/m) indicating metasedimentary formations. In the same vein, the segments characterised by (red to pink colours) indicates high magnetic intensities with values in the range of (0.04 to 0.05 nT/m)signifying the metavolcanics formations. The produced HGM map is quite similar to the FVDR map (Fig. 4b). The HGM grid has also been subjected to the CET(fig.5b) and rose diagram (fig.6b) analysis and both major and minor trendswere also uncovered along the NE–SW, N-S, E-W and NW-SE directions respectively.

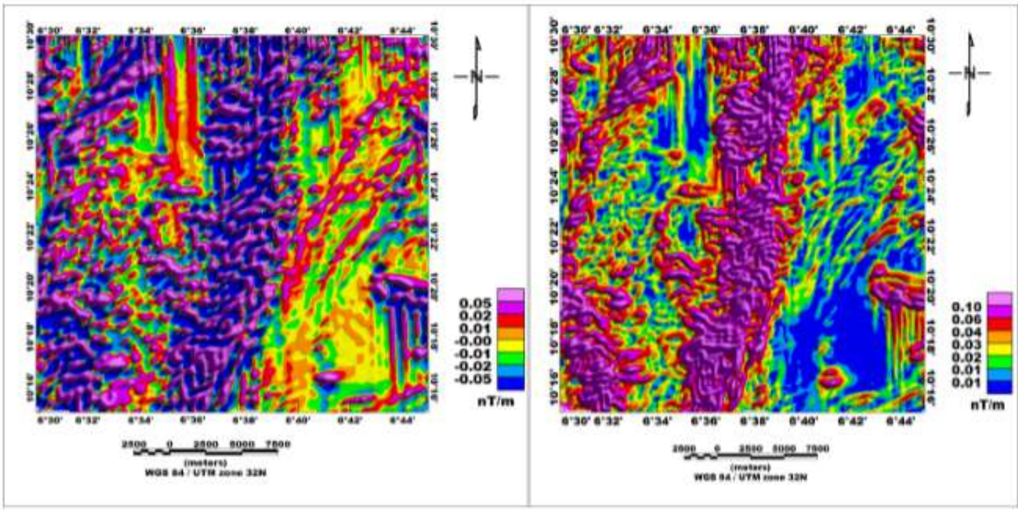

Fig. 4: (a) FVDRanomaly map **(b)** HGM anomaly map

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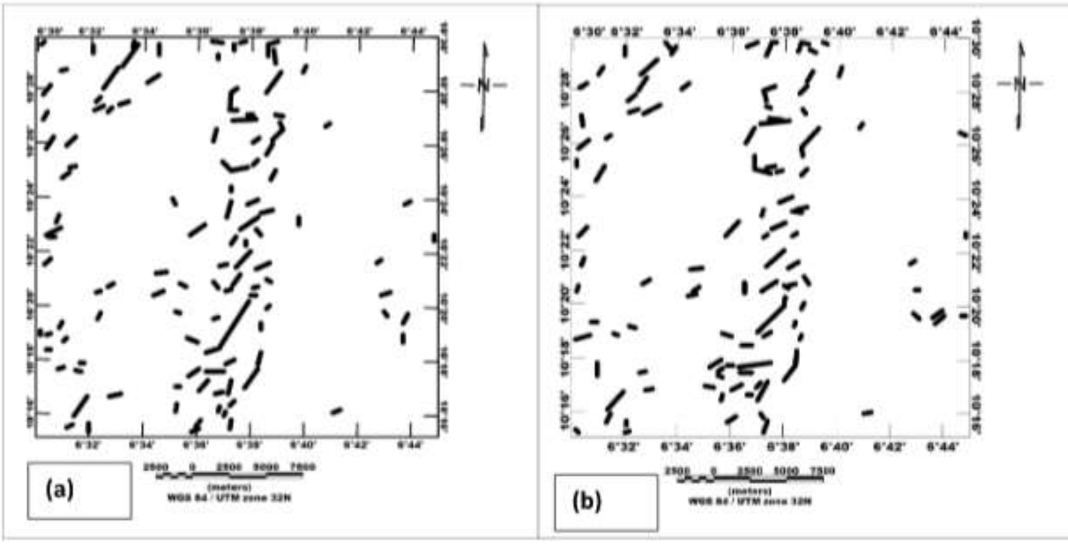

Fig. 5: (a) FVDRlineaments map **(b)** HGM lineaments map

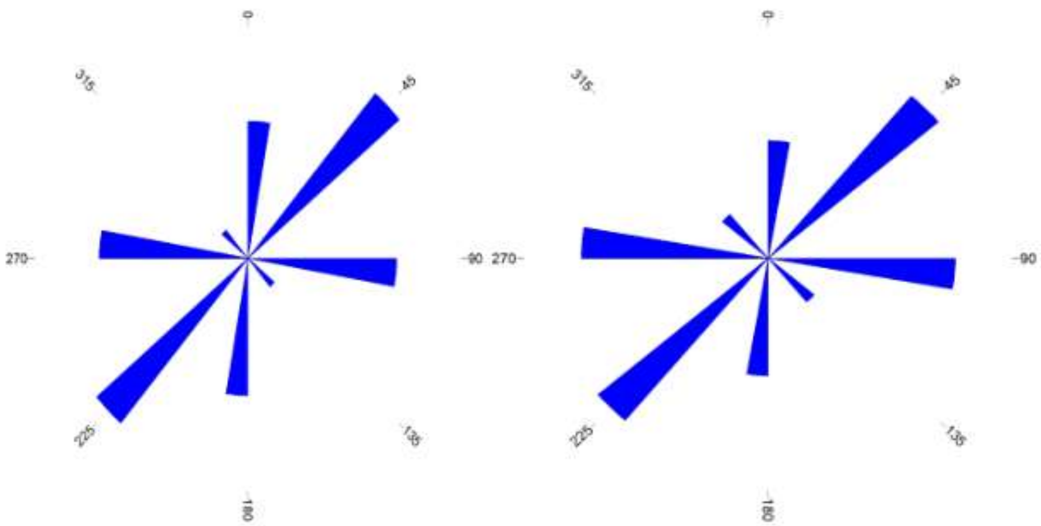

Fig. 6: (a) FVDR rose diagram **(b)** HGM rose diagram

VI. DISCUSSIONS ON THE BASEMENTS DEPTHS ESTIMATE

Analytic Signal Basement Depths Estimate

The analytic signal method was adopted to appraise the basement depths of the area under study. The ratio of the analytic signal of the residual magnetic intensity components (fig.7a) and the analytic signal of the first vertical derivative (fig.7b) of the residual magnetic intensity components were appraised as depicted (fig.7c). The deduced basement depths map revealed deeper metasedimentary and shallow metavolcanics interface with values in the range 108.4 to 322.4 m. The deeper (thicker) segments are covered by the (magenta to blue colours) which are predominantly found along the NNW, NE, SE and narrow portions in the SW of the study area. On the other hand, the (green to pink colours) represents the depths of the average to the thinner magnetic features. These could be seen as magnetite intrusions within the study area.

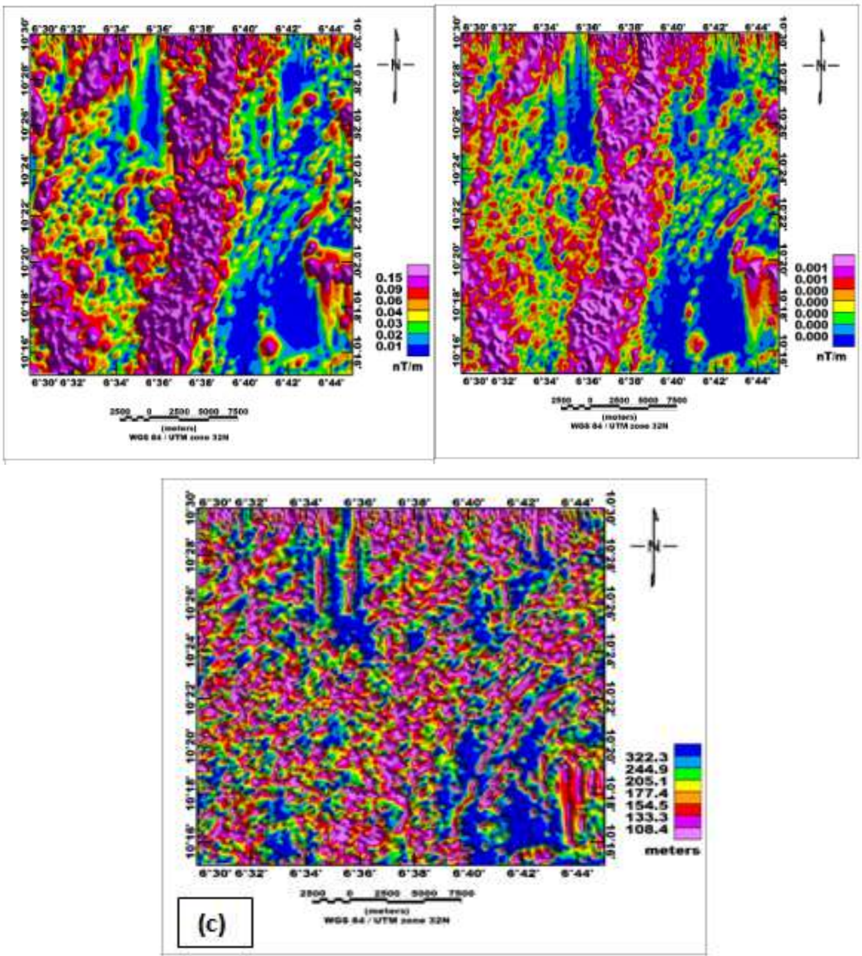

Fig.7: Shaded colour maps **(a)** Analytic signal of the residual magnetic intensity **(b)** Analytic signal of the first vertical derivative **(c)**Basement depths deduced from AS method

VII. CONCLUSIONS

Aeromagnetic dataset covering Allawa and its environs was analysed to depicts the subsurface geologic features and alsothe depths to the magnetic source anomalies were appraised. The delineated subsurface geologic features are perhab interpreted as faults, folds and fractures that may be pathways for numerous mineralised materials along the dissected major and minor trends of NE–SW, N-S, E-W and NW-SE directions respectively. Furthermore, the depths to the magnetic sources anomalies were estimated in the range of 108.4 to 322.3 m. Therefore, the findings from the study has shed more light in the understanding of the geologic framework of the present study area.

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