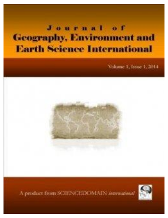

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Delineating Mineralisation Zones within the Keffi-Abuja Area Using Aeromagnetic Data

J. Andrew[1], A. Alkali[1*], K. A. Salako[1] and E. E. Udensi[1]

[1]Department of Physics, Federal University of Technology Minna, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Author EEU designed the study, performed the statistical analysis, write the first draft of the manuscript. Authors AA and KAS managed the analyses of the study. Author AA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Delineating mineralisation zones within Keffi- Abuja North Central, Nigeria was carried out to identify structures and to suggest the viability of the basin for Mineralization Zone potentials in the survey area. Aeromagnetic data over the study area bounded by latitudes N8°50'N to 10°00'N and longitudes 7°00'E to 8°00'E was carried out using First Vertical Derivative, Horizontal Derivative, Second Vertical Derivative and Analytical Signal. The First Vertical Derivative, map shows a dominant NE trend of the structures within the study area, The Horizontal Derivative reveals those anomalies that are trending in the horizontal (x-direction) clearly, Second Vertical Derivative map identify regions around central to west part of the study area which correspond to Kagarko, Kafin and Abuja to be areas with high mineralization zone, smaller mineralisation zones are also identified to NW region around Bishini, SW within Kwali and Keffi in SE region. Analytical signal identify areas with high amplitude ranges from -0.010m to 0.141m within the study area. The high amplitude structures are to the central and western portion around the Kagarko, Kafin and Abuja

**Corresponding author: E-mail: aisha.alkali@futminna.edu.ng;*

axis. This made it possible to delineate the various mineralisation zones around the study area. Map shows that central to western portions around the Kagarko, Kafin and Abuja are particularly promising for mineralization.

Keywords: Mineralization zone; first vertical derivative; second vertical derivative; horizontal derivative and analytical signae.

1. INTRODUCTION

This present study is aimed at Delineating Mineralisation Zones within the Keffi-Abuja area using Aeromagnetic Data. The current high rate of unemployment coupled with the over reliance of the country on the oil sector as the major source of revenue calls for diversification, to incorporate other sectors. Mineral are of importance to the economy of a nation if discovered and harnessed As this will create a productive environment for business opportunities, boast the nation's economy and provide raw materials for industrial uses which might in turn reduce the level of unemployment thereby eradicating poverty in Nigeria. Exploitation of mineral resources has assumed prime importance in several developing countries including Nigeria. Nigeria is endowed with abundant mineral resources, which have contributed immensely to the national wealth with associated socio-economic benefits. Mineral resources are of important source of wealth for a nation but before they are harnessed, they have to pass through the stages of exploration, mining and processing. The study area is within the Keffi-Abuja which is known as the home of solid minerals, part of Kaduna State which also pronounce to have considerable number of solid mineral resources and of commercial quantities.

Aeromagnetic data over the study area bounded by latitudes N8°50'N to 10°00'N and longitudes 7°00'E to 8°00'E was carried out using First Vertical Derivative, Horizontal Derivative, Second Vertical Derivative and Analytical Signal. The principal objective of the research is to ascertain area with good potential for positive magnetic minerals which will serve as business opportunities and boasting the economy of Nigeria thereby eradicating poverty in Nigeria. Second Vertical Derivative map indicates areas with possible mineralization zone around Kagarko, Kafin and Abuja these are areas with possible mineralization zones. Several reports have shown that Nigeria has a lot of potential for solid minerals. [1] reported that each state in Nigeria including the Federal Capital Territory (F.C.T.) has a fair share of the country's solid mineral inventory. Map of Nigeria shows the location of the study Area (Fig. 1) and the geological map of the area (Fig. 2).

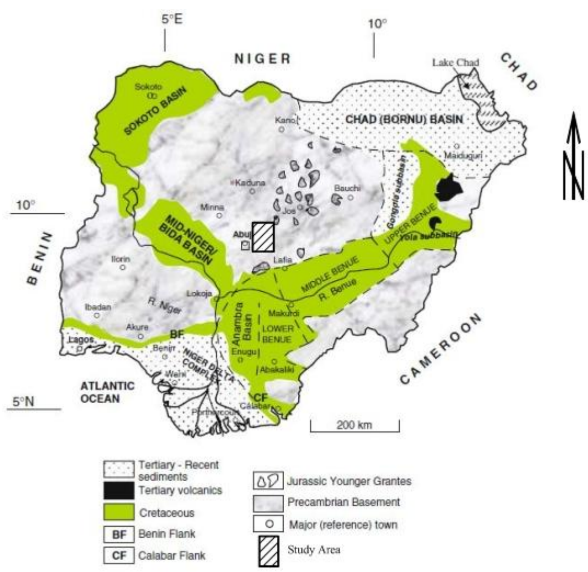

Fig. 1. Location of the Study Area on Geological Map of Nigeria [1]

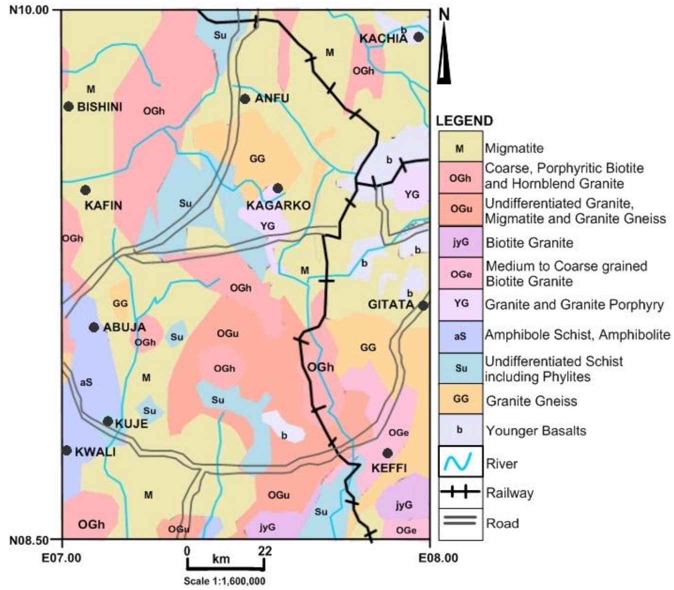

Fig. 2. Geological Map of the Study Area, Modified from NGSA [2]

Nasarawa State which forms part of the study area is known as the home of solid mineral, while Kaduna State and the F.C.T. which also form part of the study area also boast considerable amount of solid mineral resources of their own. Therefore, the study of mineralization in this area is promising. In a Basement Complex terrain such as the study area, most mineralisation are found within structural lineaments such as fractures, faults, folds, veins and dykes [3].

2. GEOLOGY OF THE AREA

The study area lies entirely within the Basement Complex of North-central Nigeria. It comprises rocks of the migmatite-gneiss and schist and generally intruded by the Pan African Older Granite rocks. The area of study forms part of the Basement Complex of Central Nigeria where a lot of work has been carried out. [4] was the first to study the geology and geography of northern Nigeria where according to him, the area of study is underlain by the Basement Complex rocks which comprises migmatite and gneisses and is intruded by granites, which he calls 'Older Granite' to distinguish them from the Younger Granites. Falconer also described the Geology of the Plateau tin fields in his work where Keffi forms part of the pegmatites of central Nigeria which is located within the Basement Complex. [5] also stated that the area is covered by undifferentiated migmatite including veins, banded and porphyroblastic gneiss, some schist and phylites. [6] divided the Basement Complex rocks of this area into meta-sediments and the Older Granites. The meta-sediments include the older rocks, which are now almost transformed into anatectic migmatites and granites.

[7] reported about the geology of the Precambrian to Lower Paleozoic rocks of the NW Nigeria. She stressed the fact that Northern Nigeria is underlain by gneisses, migmatites and meta-sediments of Precambrian age, which are intruded by series of granitic rocks of the Late Precambrian to Lower Paleozoic age. The older rocks are represented by a series of older meta-sediments and gneisses believed to be of Birrimian age or older. These rocks have been variously metamorphosed and granitised through at least two tectonometamorphic cycles so that they have been largely converted to migmatite and granite gneisses. The Early Archean (7.35 Ga) to Late Archean (2.5-2.7 Ga) Migmatite-Gneiss-Quartzite Complex forms the basement in this region. The Basement Complex rocks (granites, granite-gneiss, schist and migmatite,) have weathered to clayey-sandy cover and laterite cap, Obaje 2009. The general fold pattern consists of open and a symmetric flexure of low plunges to the north and northwest with fold axis of NS strike pattern. The entire shield is a southern prolongation of the Pan African domain of the central Hoggar to the north whose geodynamic evolution has been linked to the continent-continent collision approximately 600 Ma, [8] and [9]. The products of this event in Nigeria consist of granites, their associated

intermediate (charnockitic, monzonitic syenite) rocks, acid and dolerites, as well as extensive migmatisation and granitisation of the Pan African Basement Complex.

[10] stated that most mineral deposits are related to some type of deformation of the lithosphere and most theories of ore formation and concentration embody tectonic or deformational concepts. They also stated that some lineament patterns have been defined to be the most favourable structural conditions in control of major regional lineaments, the intersection of major lineaments or both major (regional) and local lineaments, lineaments of tensional nature, local highest concentration (or density) of lineaments between echelon lineaments associated with circular features. Linear features are clearly discernable on aeromagnetic maps and often indicate the form and position of individual folds, faults, joints, veins, lithologic contacts and other geologic features that may lead to the location of individual mineral deposits. They also indicate the general geometry of subsurface structures of an area thereby providing a regional pattern.

3. MATERIALS AND METHODS

The data for the study were obtained from aeromagnetic maps of the total magnetic field intensity in half degree sheets acquired from the Nigeria Geological Survey Agency (NGSA). These surveys were conducted between 1974 and 1976 covering nearly the entire country. The data were collected at a nominal flight altitude of 500 ft (about 152 m), with flight line trending NNW-SSE at profile spacing 2 km apart. The maps are on a scale of 1:100,000 and contoured at 10 nT intervals. A total of 340 maps cover the entire country. The actual magnetic values of the study area were reduced by 25,000 gammas before contouring the maps, [5]. This implies that a value of 25,000 gammas should be added to the contour values so as to obtain the actual magnetic field at a given point. A correction based on the IGRF epoch date 1 January, 1974 was included in all the aeromagnetic maps published by the Geological Survey Agency of Nigeria, [5]. Magnetic data comprising of six (6) map sheets, within the north central part of Nigeria were acquired. These magnetic data was digitised on a 19 x 19 grid system using the visual interpolation method of digitisation of maps. The data from the six (6) maps were then combined into a single data called the 'super data' from which the super map (composite Total Magnetic Intensity contour map) was produced using a contouring package programme, surfer version 10. Another programme (Oasis montaj) was used to produce the Total Magnetic Intensity (TMI) map of the area in colour aggregates. The TMI map was analysed qualitatively to interpret closures, trends and discontinuities of magnetic anomaly over the area, other filters were applied to the magnetic data including Derivatives (horizontal and vertical derivatives) and analytical signal, in order to further interpret and delineate the mineralisation and structural boundaries in the study area.

3.1 Methods

3.1.1 Derivatives

Derivatives tend to sharpen the edges of anomalies and enhance shallow features. The derivative maps are much more responsive to local influence than broad or regional effects and therefore tend to give sharper pictures than the map of the total field intensity. Thus the smaller anomalies are more readily apparent in cases of long regional disturbances. In fact, the first derivatives (both horizontal and vertical) are used to delineate high frequency features more clearly where they are shadowed by large amplitude, low frequency anomalies. The derivatives in the frequency domain are represented by the following equation:

$$L(r) = r^n \tag{1}$$

Where n is the order of differentiation, and r is the wavenumber (radians/ground unit).

The first vertical derivative (FVD) is used to delineate high frequency features more clearly where they are shadowed by large amplitude, low frequency anomalies.

The second vertical derivative (SVD) enhances the anomaly boundaries of near surface effects. They are a measure of curvatures and large curvatures are associated with shallow anomalies. The SVD is obtained from the differences between nearby first derivatives. These filters are considered most useful for defining the edges of bodies and for amplifying fault trends. In mathematical terms, a vertical derivative can be shown to be a measure of the curvature of the potential field, while zero SVD contours defines the edge of the causative body. Thus, the SVD is in effect a measure of the curvature, which is the rate of change of nonlinear magnetic gradients. The zero magnetic contours of the second vertical derivative often coincide with the lithologic boundaries while positive and negative anomalies often match surface exposures of the mafic and felsic rocks respectively.

3.2 Analytical Signal

This is a filter applied to magnetic data which is aimed at simplifying the fact that magnetic bodies usually have a positive and negative peak associated with them, which in many cases makes it difficult to determine the exact location of the causative body.

[11] has shown that for two-dimensional bodies, a bell-shaped symmetrical function can be derived which maximizes exactly over the top of the magnetic contact. This function is the amplitude of the analytical signal. The only assumptions made are uniform magnetisation and that the cross section of all causative bodies can be represented by polygons of finite or infinite depth extent. This function and its derivatives are therefore independent of strike, dip, magnetic declination, inclination and remanent magnetism. The two-dimensional analytical signal, A, of a potential field anomaly can be defined, [12].

$$A(x,y) = \left[\frac{\partial M}{\partial x}\right]\hat{x} + \left[\frac{\partial M}{\partial y}\right]\hat{y} + \left[\frac{\partial M}{\partial z}\right]\hat{z} \qquad (2)$$

Where M = Magnetic field.

The analytical signal amplitude can now be calculated as:

$$F(x,y,-h) = \frac{h}{2\pi}\iint \frac{F(x,y,o)\partial x \partial y}{\left\{(x-x')^2+(y-y')^2+h^2\right\}^{1/2}} \qquad (3)$$

Where F (x', y', -h) = Total field at point P (x', y', -h) above the surface on which F (x, y, o) is known.

h = Elevation above the surface.

4. RESULTS AND DISCUSSION

4.1 TMI Contour Map

The TMI contour map (Fig. 3) shows variations in magnetic intensity across the area in contours. High contour values indicate areas of high magnetic intensities while low contour values indicate low magnetic intensities. TMI contour map (Fig. 3) reveals a NE-SW trend, however, E-W trends are observed around Bishini and Kafin area in the NW portion and around Keffi in the SE portion. Also, NW-SW trend is observed around Kagarko in the central portion of the area. These trends of E-W NW-SE and NE-SW correspond with the structural trends of the Basement Complex of Nigeria as reported by [13] and [3]. Magnetic closures numerous magnetic closures dot the entire survey area. Both magnetic highs and lows closures were observed and are elliptical in shape. The magnetic high closures are marked **H** while the magnetic low closures are marked **L** (Fig. 5). The magnetic high closures dominate the area around Bishini and Kafin in the north-western portion and around Kuje, Keffi and Gitata area in southern and south-eastern portions. On the other hand, the magnetic low closures dominate the central portion around Kagargo and the north-eastern portion around Kachia. Magnetic discontinuity refers to fault lines or joints that cut across the study area. One major discontinuity exists in the study area. TMI map revealed this discontinuity running from the south-western portion of the study area around Kwali to the eastern portion, just above Gitata. It is typified by a set of parallel running contour lines trending in the NE-SW direction. This discontinuity is probably a fracture filled with sediments or low magnetic minerals as indicated by the low magnetic intensity that characterized it. The discontinuity is marked **'dd'** (Fig. 5). This discontinuity may be related to the Romanche fracture (Fig. 6) which is one of the four major Atlantic Fracture Zones that abut the West African coast into the Nigerian Basement Complex, [14]. These Atlantic Fracture Zones signified an ancient zone of weakness in the Nigerian Basement Complex.

4.2 TMI Map in 3D (Surfer 10)

This represents the total magnetic intensity map in 3-dimension (Fig. 4). It shows the variation in magnetic intensities across the area as a series of undulations and depressions. Undulations indicate high magnetic intensities represented by brownish colourations while the valley-like depressions indicate low magnetic intensities also represented by bluish colourations.

4.3 First Vertical Derivative (FVD)

The first order derivative can be either vertical or horizontal. The first vertical derivative FVD, (Fig. 7) map shows a dominant NE-SW trend of the structures within the study area, NW-SE trends as well as E-W trends are also observed in the study area. The horizontal derivative (Fig. 8) on the other hand reveals those anomalies that are trending in the horizontal (x-direction) more clearly.

4.4 Second Vertical Derivative (SVD)

The Second vertical map (Fig. 10) reveals the boundaries of those shallow anomalies clearly. This made it possible to delineate the various mineralisation zones. The map shows that the central to western portions around the Kagarko, Kafin and Abuja are particularly promising for mineralisation. There are also smaller mineralisation zones to the NW around Bishini, SW around Kwali and Keffi in the SE region.

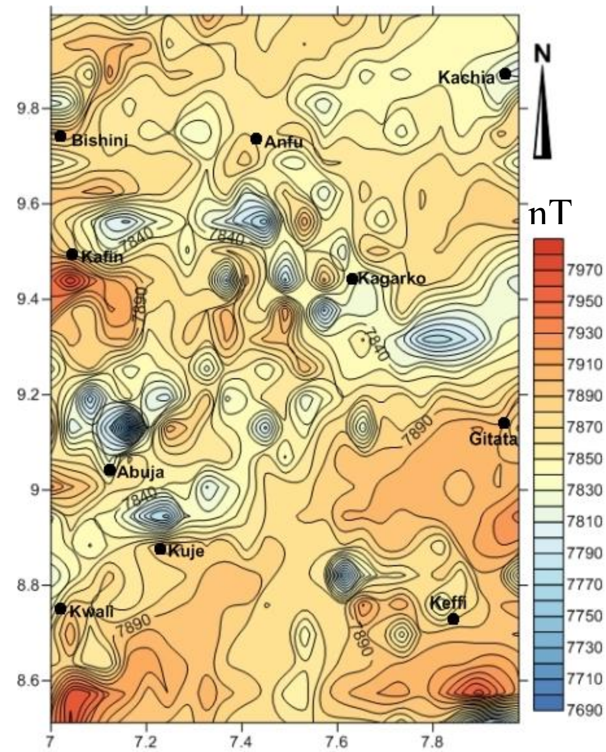

Fig. 3. Total Magnetic Intensity Contour Map of the Area Contoured at 10 nT interval, after 25,000 nT have been Removed

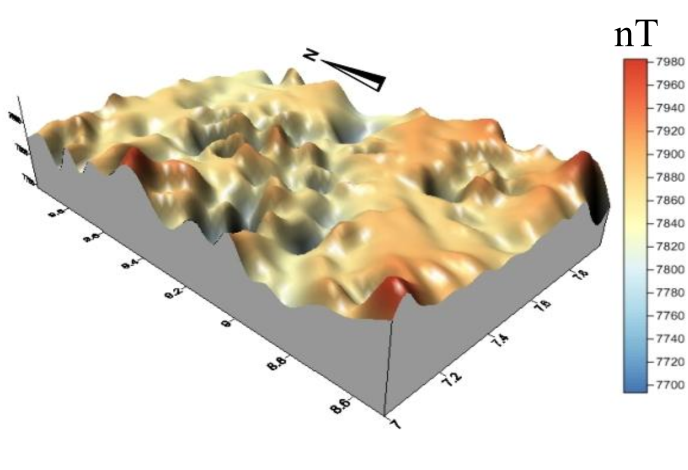

Fig. 4. Total Magnetic Intensity Map of the Area in 3D

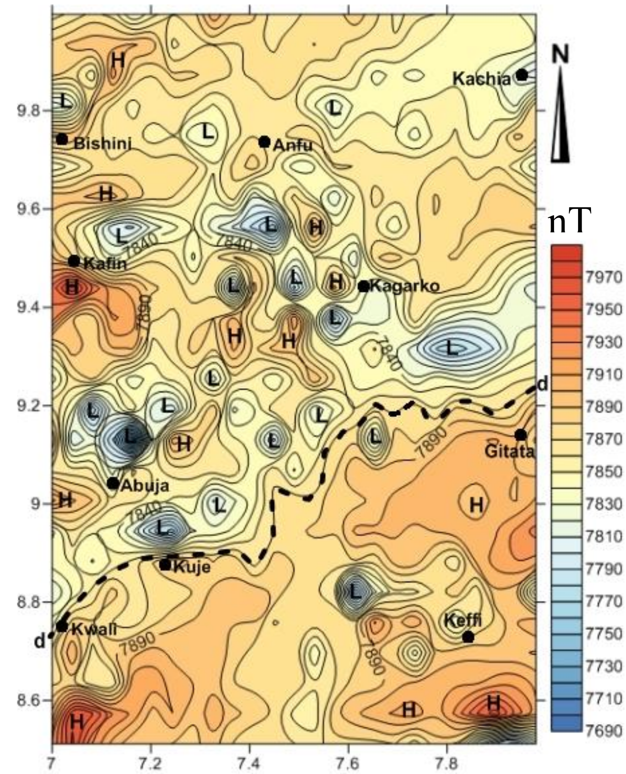

Fig. 5. Magnetic Closures and Discontinuity within the Study Area H = Magnetic high, L = Magnetic low, dd = Discontinuity

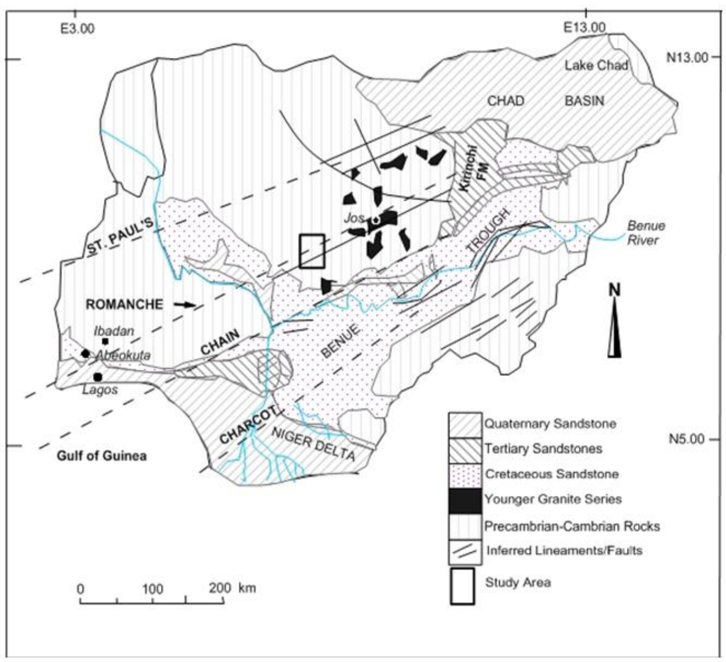

Fig. 6. Geological Map of Nigeria showing the Atlantic Fracture Zones, Modified after [13]

4.5 Analytical Signal

The analytical signals map (Fig. 11) shows that the amplitude ranges from -0.010m to 0.141m within the study area. The map reveals that several high amplitude structures dot the survey area. However, the high amplitude structures are to the central around Kagarko, and western portion within Kafin and Abuja axis. The high amplitude areas represent areas of later tectonic activities where magma intruded into the pre-existing rocks and solidify in the fractures left by earlier tectonic activities. These high amplitude areas correlate with the various mineralisation zones deduced from the Second Vertical Derivative map indicating that the minerals might have been enriched by the late magmatic fluids that accompanied and solidified in the fractures situated within the pre-existing rocks.

4.6 Lineament

The lineament maps (Figs. 7 and 8) produced showed a dominant NE-SW orientation and a less dominant E-W and NW-SE orientations. These lineament trends quite agree with the general structural trends of the Nigerian Basement Complex as reported by various workers. Also, a comparison of the lineament map produced from the First Vertical Derivative (Fig. 7) map and the lineament map of the area (Fig. 9) showed similarities in terms of the orientation of the lineaments. Similarly, the presence of multiple structural trends in the area attests to the occurrence of multiple tectonic episodes within the Nigerian Basement Complex. The lineament map shows that the central and western portions around Kagarko, Kafin and Anfu have high lineament densities, which coincides with the major mineralisation zones in the area. Hence the presence of lineaments in an area is related to the occurrence of mineralisation in that area.

4.7 Mineralization Zones

Based on the result of the SVD, the boundaries of the anomalies are clearly defined. Six (6) possible mineralisation zones marked **A-F** have been isolated, (Fig. 10). Magnetic peak map (Fig. 12) show the areas where the magnetic intensities are at their peak. This further

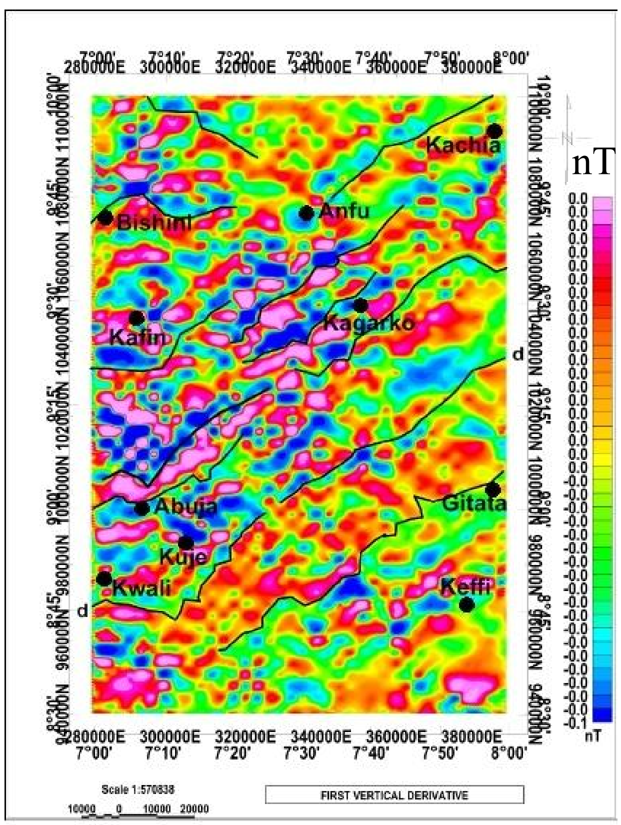

Fig. 7. Lineaments on First Vertical Derivative Map of the Area

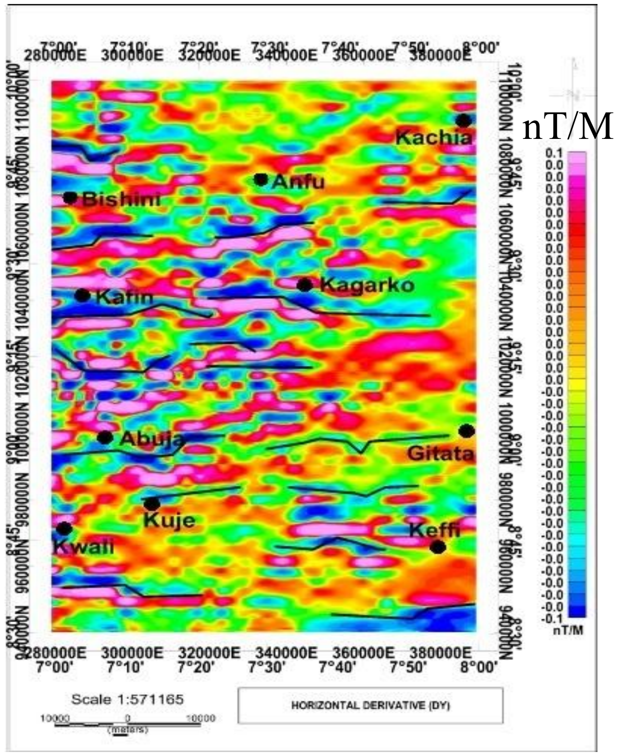

Fig. 8. Horizontal Derivative Map of the Study Area

confirmed these zones **(A-F)** as the prominent magnetic mineralisation zones in the area. Also, the result of the analytical signal (Fig. 11) and the lineament maps (Figs. 7 and 9) correlated with the SVD map (Fig. 10) shows that these mineralisation zones are areas of high amplitude and high lineament density. Areas of high lineament densities are often areas of mineral deposits especially in a basement terrain like the study area and hence, this correlates well.

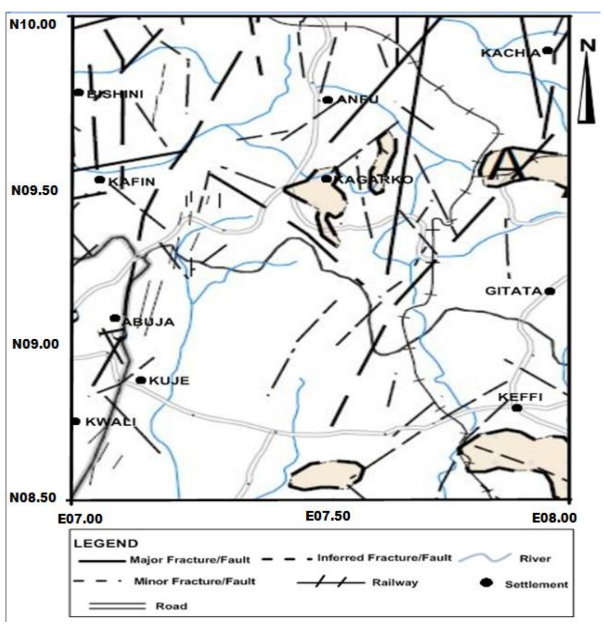

Fig. 9. Geological Lineament Map of the Study Area, [2]

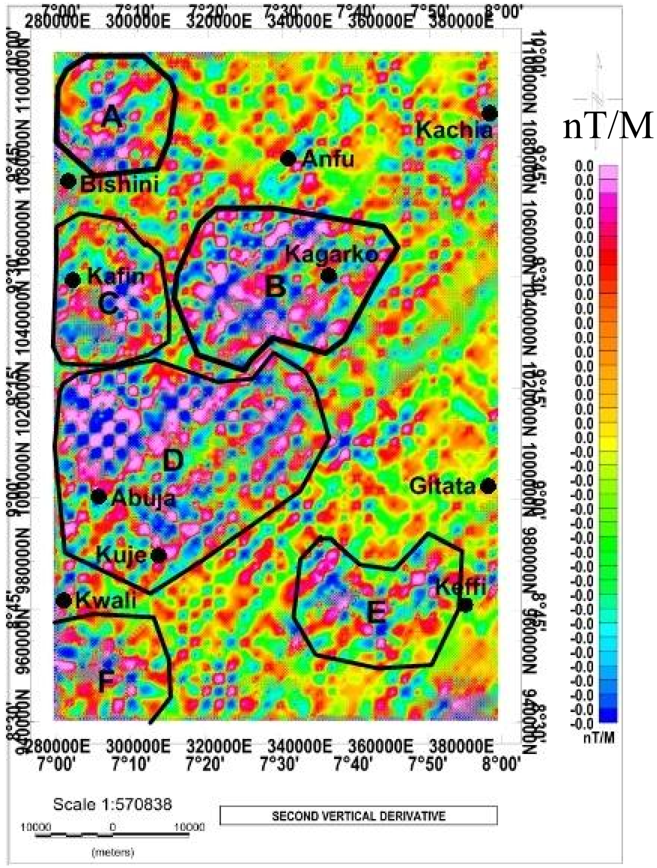

Fig. 10. Mineralization Zones on Second Vertical Derivative Map of the Area

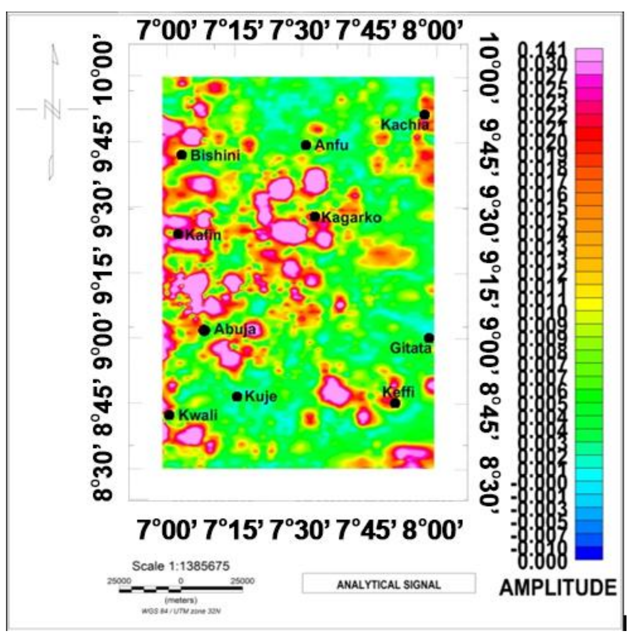

Fig. 11. Analytical Signal Map of the Study Area

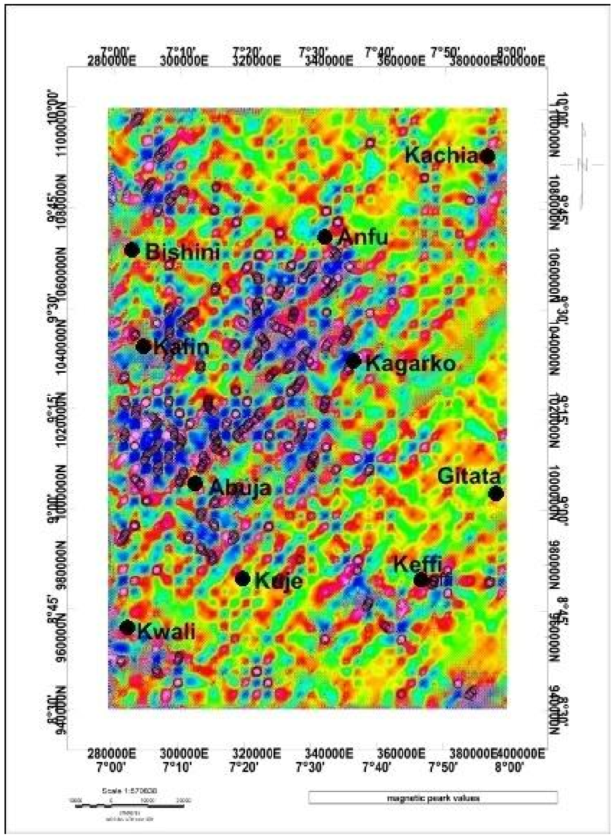

Fig. 12. Magnetic Peaks Map of the Study Area

5. CONCLUSION

The interpretation of the aeromagnetic data over the Keffi-Abuja area using various filters indicates that the area has magnetic deposits. The TMI map produced show variation in magnetic intensity across the study area which is attributed to the occurrence of various rock types with different magnetic susceptibilities. The magnetic intensity values across the study area range from 7690 nT to 7990 nT. High magnetic intensities dominate the southern to south-eastern region around Kuje, Keffi and Gitata while low magnetic intensities dominate the central to north-eastern portion around Kagarko and Kachia. The discontinuity observed on the TMI is probably a continental continuation of the Romanche fracture which is one of the four major Atlantic fracture zones that abut the West African coast into the Nigerian Basement Complex. The lineament map orientation showed a dominant NE-SW trend and a less dominant E-W and NW-SE trend within the study area. The high lineament density areas corresponded to the various mineralisation zones in the study area. The possible mineralisation zones observed have been isolated and labelled **A-F** on the SVD map. The magnetic peak map correlates well with the various mineralisation zones depicted confirming that the area has very good potential for positive magnetic minerals.

The result of the analytical signal also showed that the high amplitude areas correlate well with the possible mineralisation zones depicted indicating that these possible mineralisation zones are areas of intruded outcrops which might have been enriched by late magmatic fluid that accompanied the magmatic intrusion.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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