



## Delineation of Mineralization Zones in Part of Central Nigeria Using Analytic Signal, Second Vertical Derivative, and Centre for Exploration Targeting Plug-IN (CET)

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### ABSTRACT

A digitised aeromagnetic data comprises of sheets (144 Kakuri, 145 Kajuru, 165 Bishini, 166 Kachia, 186 Abuja, 187 Gitata, 207 Kuje and 208 Keffi) covering part of Niger, Kaduna, Nasarrawa and the Federal Capital Territory in central Nigeria with an area of  $110 \times 220 \text{ km}^2$  was acquired and analysed with the aim of delineating mineralisation zones within the area using analytic signal, second vertical derivative and structural complexity analyses of the CET. From the analytic signal map three zones were delineated; Low to fairly low magnetic zone (LM) with a gradient of 0.0024 nT/m to 0.0093 nT/m are areas associated with highly weathered rocks and areas with thin cover of sediments, metasediments, and granite because these rocks contain more than 60 to 70 percent quartz. The moderate zone (MM) with gradient 0.0093 nT/m to 0.04 nT/m associated with granite – gneiss as these rocks contain high ferromagnesian with low amount of felsic minerals. The high magnetic anomalies zones (HM) 0.2378 nT/m to 0.02349 nT/m are related to rocks that have high ferromagnesian with large amount of felsic minerals. Application of Second Vertical Derivatives (SVD) filter produces a map in which prospective zones of mineralisations and structures were mapped out. These mineralisation zones were seen to be concentrated in areas with high analytic signal of gradient 0.2378 nT/m. Application of structural complexity analysis due to CET located deposits occurrence favourable zones that coincided with zones mapped out from SVD map. Structural trends as revealed by CET Plug-IN are NE-SW, NW-SE, minor E-W and N-S trends.

**Keywords:** Mineralisation, Structural Complexity, Analytic Signal and CET

### 1.0 INTRODUCTION

Large scale aeromagnetic surveys have been used to Identify faults, shear zones and fractures that can serve as prospective hosts for most minerals and can be used as guidelines for exploring epigenetic, stress-related mineralisation in the surrounding rocks, Paterson and Reeves, (1985.) Aeromagnetic maps generally represent differences in the magnetic field of the earth arising from the magnetic characteristic of the underlying rocks (e.g. magnetic susceptibility). Sedimentary rocks have the smallest magnetic susceptibility, while

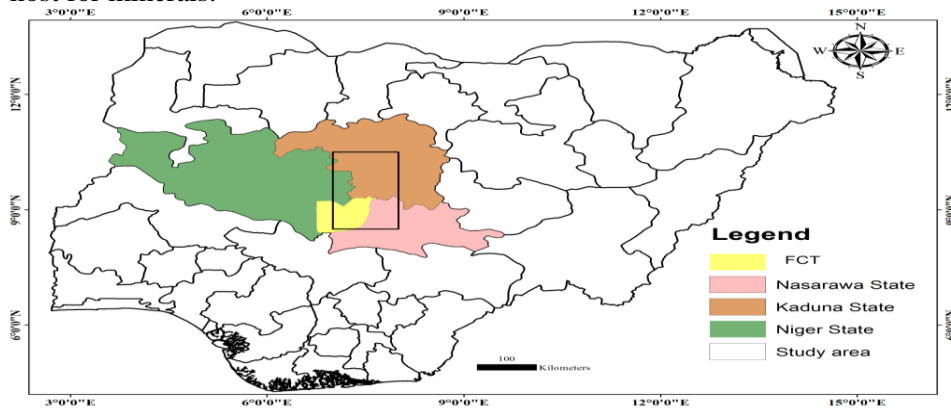
the metamorphic and the acidic igneous rocks, intermediate and basic igneous rocks have the

largest magnetic susceptibility Kearey *et al.*, (2012). Magnetic anomalies are caused by rock-containing magnetic minerals; such anomalies are generally caused by underlying (igneous and/ or metamorphic) rocks or by igneous characteristics such as intrusive plugs, dykes, sills, lava flows and volcanic centre (Gunn, 1997) as such, the present work focused on analysing and interpreting aeromagnetic data (144 Kakuri, 145 Kajuru, 165 Bishini, 166 Kachia, 186 Abuja, 187 Gitata, 207 Kuje and 208 Keffi) covering part of Niger, Kaduna,

Nasarrawa and the Federal Capital Territory in part of central Nigeria with an area of  $110 \times 220 \text{ km}^2$  with the aim of delineating mineralisation zone and structural complexity map of the area since complex structural areas area usually host for minerals.

**1.1 Location of the Study Area**

The study area is bounded by latitudes  $08^{\circ}30' \text{ N}$  and  $10^{\circ}30' \text{ N}$  and longitudes  $07^{\circ}00' \text{ E}$  and  $09^{\circ}00' \text{ E}$  (Figure 1) and it falls within three states in Nigeria and the FCT namely Kaduna, Niger, and Nasarrawa.



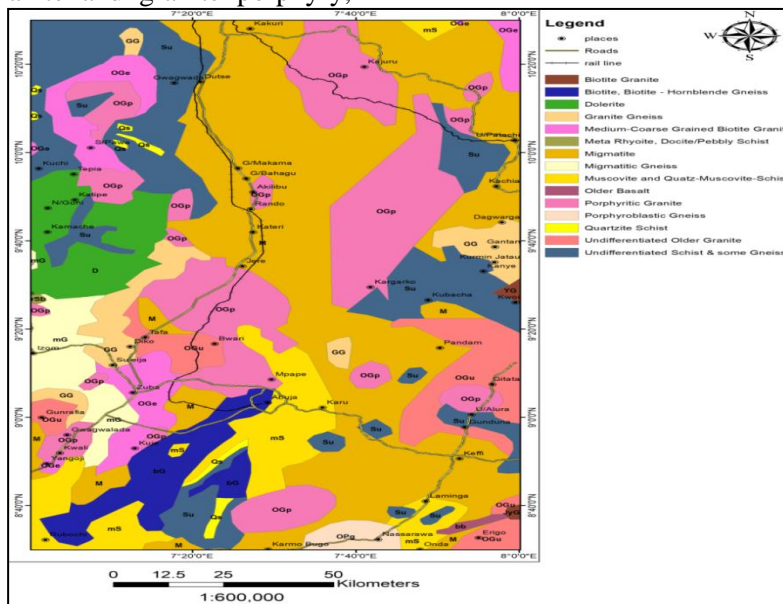
**FigureFig. 1: Location of Study Area on Nigeria Map**

Nasarrawa and the Federal Capital Territory (FCT).

**1.2 Geology of the Study Area**

The predominant rock type in the area of study is the Migmatite which almost covered the entire area with an isolated occurrence of younger basalt, granite and granite porphyry,

coarse Porphyritic hornblende granite, medium to coarse grained biotite granite, undifferentiated granite, Migmatite and granite gneiss, Amphibolites schist and amphibolites, undifferentiated schist including phillites and granite gneiss (Figure:2)



**Figure 2: Geologic map of the area (NGSA, 2006)**

**2.0 MATERIALS AND METHODS**

**2.1 Source of Aeromagnetic Data**

The Aeromagnetic Data that comprises eight (8) map sheets (144 Kakuri, 145 Kajuru, 165 Bishini, 166 Kachia, 186 Abuja, 187 Gitata, 207

Kuje and 208 Keffi) used for this research which was obtained from Nigerian Geological Survey Agency (NGSA) Abuja is a fresh data set produced from Nigeria's biggest airborne geophysical survey ever undertaken to help

place the nation as an interesting target for explorers. The survey was conducted between 2005 and 2009 and was funded by the Nigerian Federal Government and the World Bank. Fugro Airborne Surveys conducted all of the airborne geophysical job information acquisition, processing and interpretation. Phase 1 finished in September 2007 and included 826,000 line-km of magnetic and radiometric studies flew at 500 m line spacing and 80 m terrain clearance; and 24,000 line-km of electromagnetic time-domain surveys flew at 500 m line spacing, 100 meter flight line spacing and 80 m terrain clearance using the GENESIS EM system from Fugro which was later followed by the phase 2.

## 2.2 Procedures

The procedures involved in this study include:

1. Produce Total Magnetic Intensity (TMI) map of the research region reduced to magnetic equator in color aggregate using Oasis Montaj software
2. Produce Analytic Signal map for locating outcrop regions and displaying places of likely mineralisation zones
3. Computation of Second Vertical Derivative for mineralisation areas to be mapped.
4. Complex structural analysis from the Exploration Targeting Center (CET) to map complex structural regions likely to be prospective favourable mineralisation zones

## 2.3 Analytic method

Total magnetic field intensities (TMI) analytic signal is much less sensitive to geomagnetic field inclination than the original TMI data and provides a means to analyse low latitude magnetic fields without the Reduction to pole (RTP) operator's concerns. Analytical signal is a popular gradient enhancement, which is related to magnetic fields by the derivatives. Roest *et al.*, (1992) demonstrated that the amplitude of the analytic signal can be derived using the expression from the three orthogonal gradients of the total magnetic field as:

$$|A(X, Y)| = \sqrt{\left(\frac{\delta m}{\delta x}\right)^2 + \left(\frac{\partial m}{\partial y}\right)^2 + \left(\frac{\delta m}{\delta y}\right)^2} \quad 1$$

where A(x, y) is the amplitude of the analytical signal at (x, y) and m is the observed magnetic anomaly at (x, y). While this function is not a measurable parameter, in the context of interpretation it is highly interesting as it is

totally independent of the direction of magnetisation and the direction of the Earth field (Milligan and Gunn, 1997). All bodies with the same geometry therefore have the same analytic signal. Analytic signal images and maps are helpful as sort of pole reduction as they are not subject to the instability that happens when magnetic fields are transformed from low magnetic latitudes. They also describe source positions irrespective of any remnant source magnetization (Milligan and Gunn, 1997).

## 2.4 Vertical Derivatives

Vertical derivative (or alternatively named vertical gradient) filters preferentially amplify short-wavelength components of the field at the expense of longer wavelengths (Foss, 2011). Vertical derivative filters are generally applied to gridded data using FFT (Fast Fourier Transform) filters. Various vertical derivatives of the magnetic field can be computed by multiplying the amplitude spectra of the field by a factor of the form:

$$\frac{1}{n} \left[ (U^2 + V^2)^{\frac{1}{2}} \right]^n \quad 2$$

Where n is the order of the vertical derivative, (U, V) is the wavenumber corresponding to the (x, y) directions respectively. The first vertical derivative is physically equivalent to measuring the magnetic field simultaneously at two points vertically above each other, subtracting the data and dividing the result by the vertical spatial separation of the measurement points. The second vertical derivative is the vertical gradient of the first vertical derivative and so on. The formula for the frequency response of such operations demonstrates that the method increases high frequencies compared to low frequencies and this is the justification for the application of the derivative process that removes long-wavelength regional effects and resolves the effects of adjacent anomalies. The computation of the first vertical derivative in an aeromagnetic survey is equal to the observation of the vertical gradient directly with the magnetic gradient and has the same advantages, namely the enhancement of shallow sources, the elimination of deeper ones and a better resolution of closely spaced sources.

The second vertical derivative has much more resolving power than the first vertical derivative,

but requires high quality data as its application give rise to greater enhancement of high frequencies results in greater enhancement of noise. Derivatives of higher orders are virtually never used to produce interpretation products (Gunn *et al.*, 1997a).

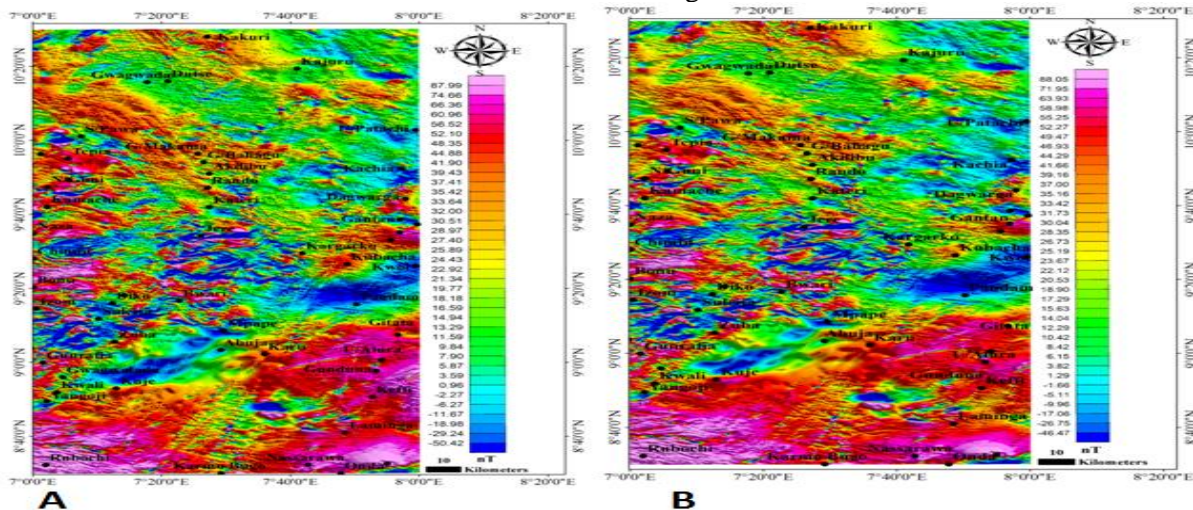
**2.5 Complex Structural Analysis**

Centre for Exploration Targeting (CET) grid analysis is a suit of algorithms that offers functionality for enhancement, lineament detection and structural complexity assessment of prospective potential field data (Holden *et al.*, 2008; core *et al.*, 2009). This method automatically delineates lineaments and identifies promising areas of ore deposits through outlining convergence regions and also the divergence of structural components using several statistical measures, including texture analysis, lineation delineation, Vectorisation and structural complexity analysis to produce contact occurrence density maps of an area. This method identifies magnetic discontinuities using combination of texture analysis and bilateral symmetric feature detection Geosoft, (2012).

**3.0 RESULTS AND DISCUSSION**

**3.1 Total Magnetic Intensity (TMI) Map and TMI Reduced to the Equator Map**

The total magnetic intensity map (Figure 3A) reveals variation in magnetic intensity of anomalies across the study area from south to the north and from the east to the west. The map (Figure 3A) exhibits some positive (red coloured) and negative (deep blue coloured) anomalies. The map also revealed prominent (red coloured), anomalies around southern part of the study area particularly in areas around Rubuchi in the extreme south west through Nasarrawa to Onda, Laminga, Keffi, Ganduma, UngwarAlura and Gitata in the south western part of the map. The positive (red coloured) anomalies are also observed in area around the central portion of the map to the western extreme end of it particularly in areas around North of Bwari to the western end. A closer look at the two maps (Figure 3A and 3B) reveals the changes in the size of the negative and positive anomalies in TMI reduced to equator map compared to the TMI map. Also, a closer look at TMI map reduced to equator (Figure 3B), the negative closure with low frequency and low amplitude (blue coloured) anomaly that extend from south of Mpape to Kuje having NE-SW trend is now shrink in size and dimension as compared to the TMI map (Figure 3A) where the same anomaly with similar trend have a larger dimension.



**Figure 3: TMI (A) and TMI Reduced to Equator (B) Maps of the Area**

**3.2 Regional and Residual Map**

TMI reduced to equator was upward continued to a depth of 70, 000 km which give a grid that represent our regional grid having northwest to south east magnetic trend (Figure 4A) and this

grid was subtracted from the TMI reduced to equator grid and the resultant grid is the residual grid (Figure: 4.B). A closer look at the residual map (Figure: 4.B) reveals the central portion of the study area from west of Kagarko to

Kataridown to Abuja toward the western end of the map having alternating occurrence of red

(positive) anomalies and blue (negative) magnetic anomalies

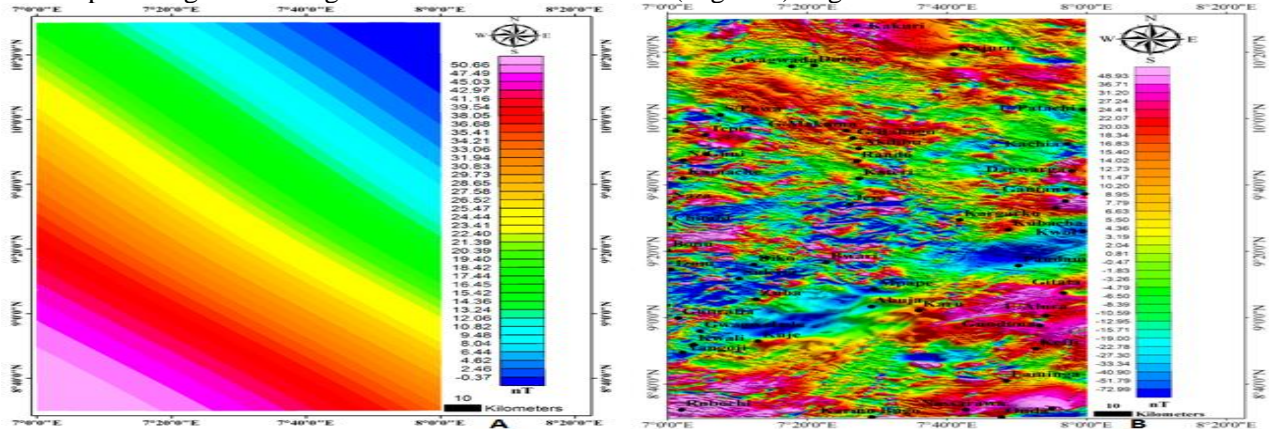


Figure 3: Regional (A) and Residual (B) Map of the Area

anomalies that dots the central area almost having magnetic anomaly trend of east west. Areas around Kakuri to North of Kajuru are now having red (positive) anomalies as compared to the total magnetic field map reduced to equator (Figure 3B). Also, the large positive magnetic anomaly that extend from south of Abuja in RTE map (Figure 3B) has now been reduced and have high magnetic intensity around Rubuchi in the extreme south western part of the study area.

**3.3 Analytic Signal Map**

The analytical signal or total gradient is formed by a combination of the horizontal and vertical gradients of the magnetic anomaly. It is based on the calculation of the first derivatives of magnetic anomalies to evaluate the characteristics of the source. This filter was applied to magnetic data and was designed to simplify the fact that magnetic bodies usually have a positive and negative peak associated with it, which in many instances makes it difficult to determine the exact location of the causative body. The analytic signal map (Figure 4) accentuates the variability in magnetisation of magnetic sources in the research location and highlights discontinuities and anomaly textures. This filter was applied to the airborne anomaly magnetic field data produced map, comparing

this map (Figure 4), with the total magnetic field (Figure 3A), the difference is immediately obvious with the structures along eastern part of the map down to the south. These structures are also observed around the central portion of the area to north. The analytic signal amplitude maximises over the edge of the magnetic structures as a result, the high magnetic anomalies zones are associated with highly rich ferromagnesian-bearing rocks with minor felsic minerals (Telford *et al.*, 1990). Therefore, the AS map (Figure 4) exhibited three different magnetic zones in this area of study. Low to fairly low magnetic zone (LM) with a gradient of 0.0024 nT/m to 0.0093 nT/m are areas associated with highly weathered rocks and areas with thin cover of sediments, metasediments, and granite because these rocks contain more than 60 to 70 percent quartz. The moderate zone (MM) with gradient 0.0093 nT/m to 0.04 nT/m associated with granite – gneiss as these rocks contain high ferromagnesian with low amount of felsic minerals. The high magnetic anomalies zones (HM) 0.2378 nT/m to 0.02349 nT/m are related to as the rocks that have high ferromagnesian with large amount of felsic minerals.

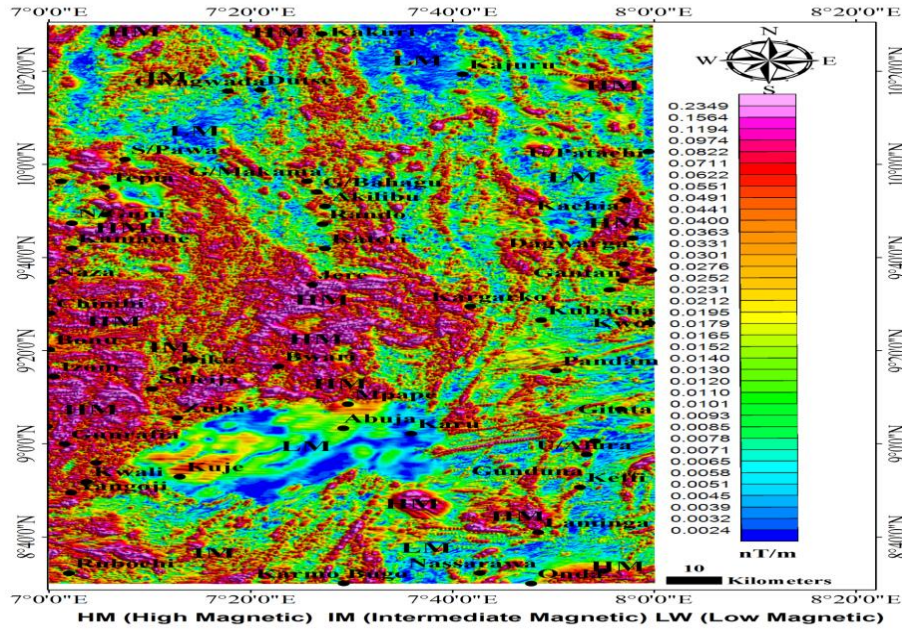


Figure 4: Analytic Signal Map with Magnetic Lows and Highs

**3.4 Second Vertical Derivative Maps**

The second vertical derivative filter was used to improve shallow anomalies while at the same time reducing regional trends. This filter is

regarded most helpful for identifying anomalies and amplifying fault patterns. The SVD map (Figure 5) obviously shows the limits of these shallow anomalies.

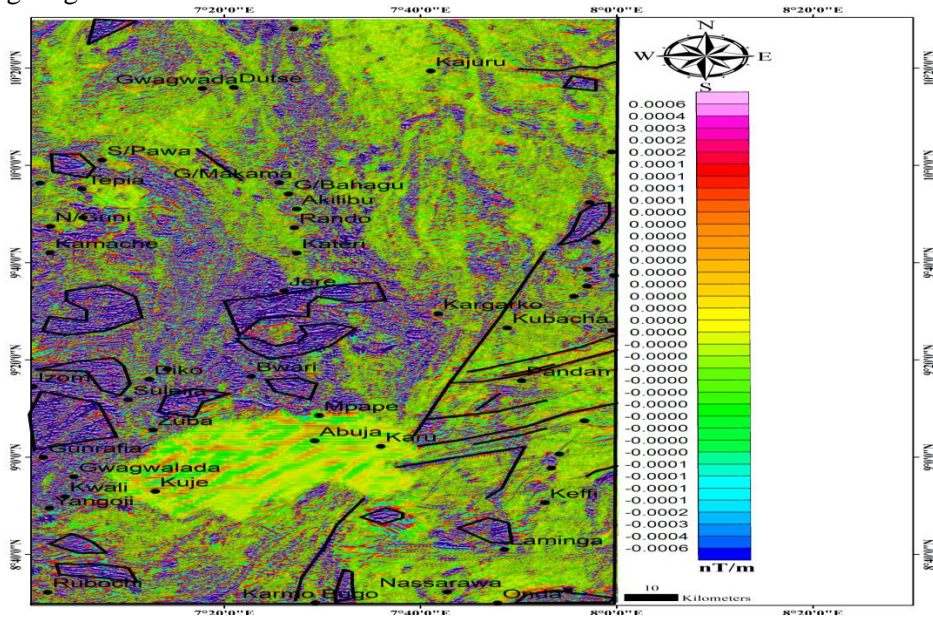


Figure 5: Second Vertical Derivative Map with Structures

This has allowed the different mineralisation areas and faults within the area to be delineated (Figure 5) in black polygons. These mineralisation zones are observed in areas around west of Kagarko towards Jere in the north of it and also down Bwari through north of Mpape in the south, toward the western part of

the study area from west of Sarkin Power to North of Tepia, areas around Naza through Chimbe and Izom down to Gunrafia in the south shows that these areas are mineralised. Areas in north of Rubuchi also showed sign of mineralisation and at extreme south eastern part of the map particularly around south of Onda

shows also that this area is mineralised with areas around north western side of Laminga (Figures 5). Toward extreme northern part of the map, around west of Kakuri and extreme western end of the map in the north also shows zones of mineralisation. A closer look at the eastern part of the map around south of Kachia to Dagwarga and areas around south eastern side of Gantan shows that these areas are also mineralised.

### 3.5 Structural Complexity Analysis

The structural complexity analysis is used to identify a favorability of deposit occurrence. This technique determines magnetic discontinuities, then defines areas of discontinuity and analyses structural connection in order to identify crossing, intersections, and change of direction in the strike. By measuring the structural contact density and strike structures variability as a heat map, it enables the selection of zones that are considered and

perceived to be prospective. When applied to the TMI reduced to equator starting with standard deviation (Figure: 6A), shows the output that reflects the distribution of the magnetic intensities of the study region. As a result, sections of discontinuity will show highest and standard deviation values. The sections identified are linked to both structural lineaments and lithological borders. The output of the phase symmetry (Figure 6B) was calculated from the aeromagnetic survey image shown in (Figure 6A). It reflects or demonstrates the local structure in the image that enables the ridges as well as the valleys to be detected. Symmetry detection identifies components of magnetic discontinuity such as lithological boundaries, faults and dykes (positive features). Figure 6B is thresholded and skeletonised. Skeletal structures are analysed to create a collection of straight line segments.

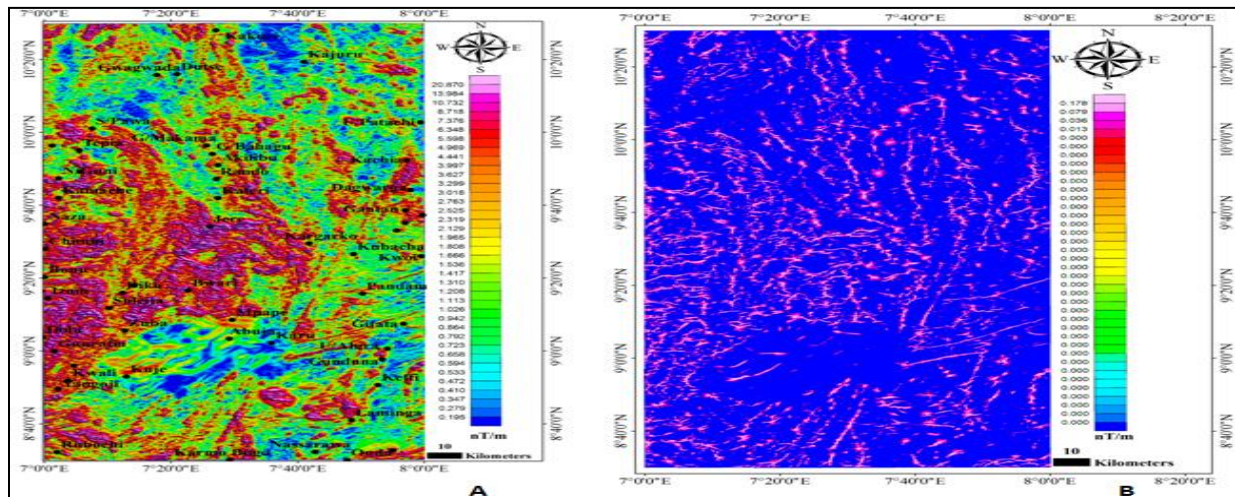


Figure 6: Standard Deviation Map(A) and Phase Symmetry Map (B)

The segment of the straight line is fitted and computed (Figure 7). Figure 8 displays the structure contact density heat map, which was produced by a set of selected intersections including crossings, junctions and corners of the identified line segments. Where the areas of linear structure intercept or change

direction represent the high prospective areas for mineralization. The line segments are used to calculate the orientation entropy of the texture. Figure 9 displays the areas of junction high density in red dots. These areas are favourable for hosting deposits in the study area and could be explored in detail.

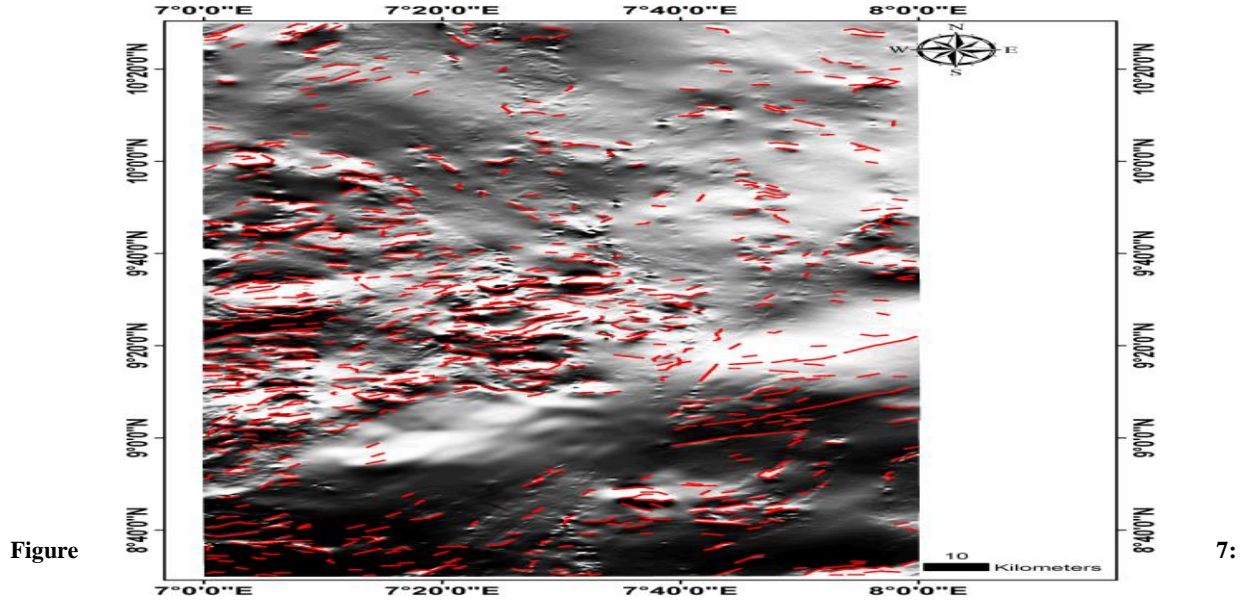


Figure 7: Vectorised Straight Line Segments Result in Red Overlaid Over Grey Scale Reduced to Magnetic Equator (RTE)

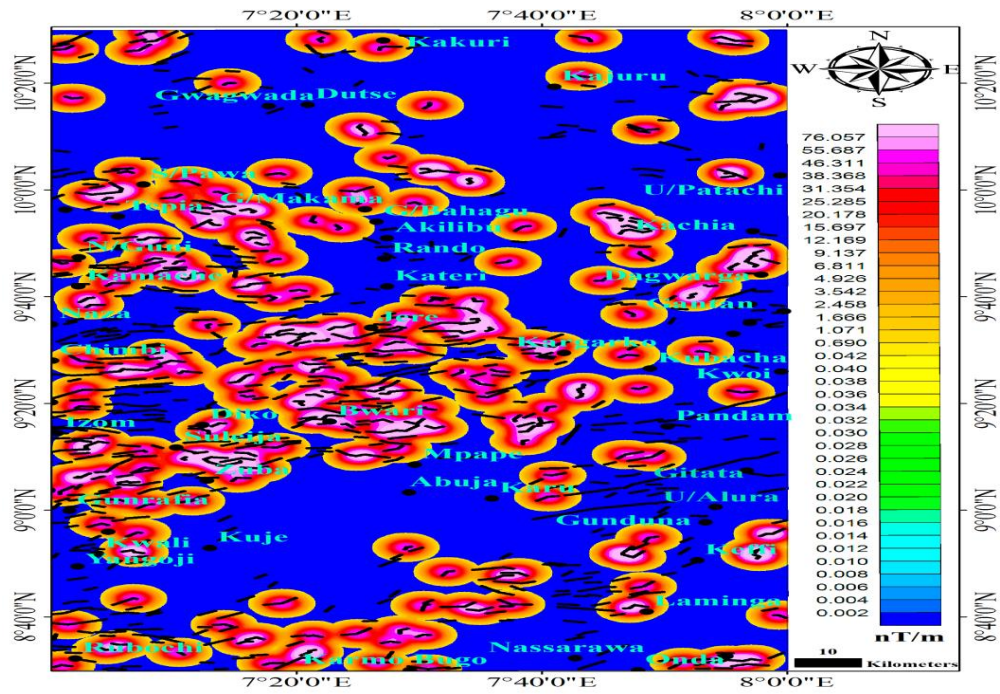


Figure 8: Contact Occurrence Map

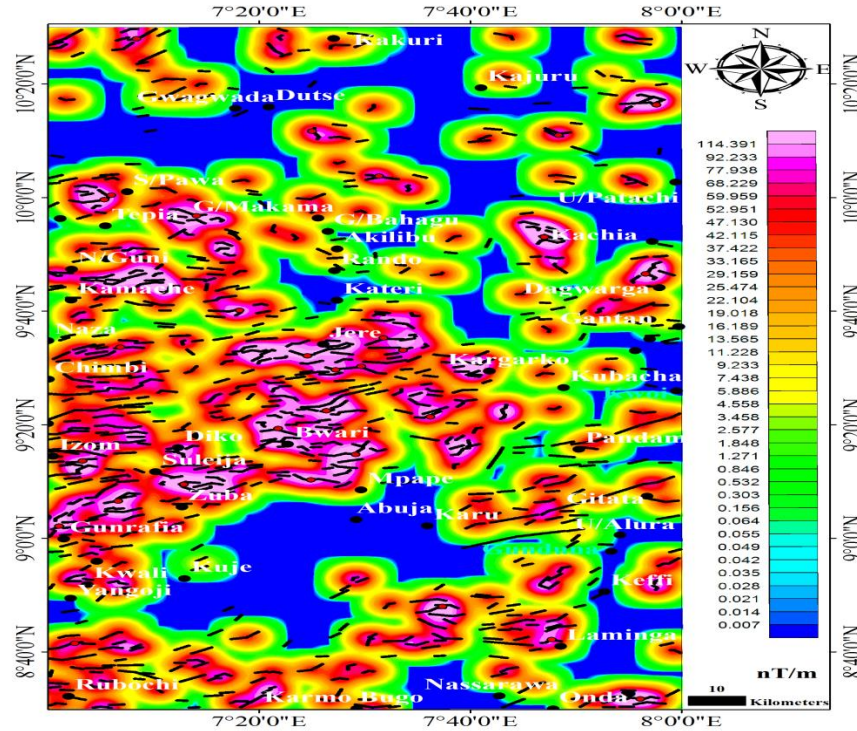


Figure 9: Orientation Density Heat Map

**4.0 CONCLUSION**

Analysis of the analytic signal (Figure 4) showed areas of high amplitude which are expected to be areas of probable large mineral deposit with gradient of 0.2349nT/m from the central part of the map to the western end of the study region. Anomalies with the same gradients dot the other sections of the area. The second vertical derivative map (Figure 5) shows the boundary of the mineralisation zones and the map also shows the major faults map out having trends of NW-SE and NE-SW within the research area, while the structural complexity analysis generated maps (Figure: 8 and 9) that selects or indicates regions of high density junctions overlaid by the structures produced. These regions are favorable for hosting minerals as they are areas of high structural density compared to second vertical derivative (SVD) map (Figure 5) verified that both maps have mineralisation zones on comparable parts of the individual maps. The structural analysis of the CET evaluation (Figure: 7) shows the study area having dominant NE-SW and NW-SE trends.

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