Mineralization Zones Delineation in Part of Central Nigeria Using Analytical Signal, Derivatives, Downward Continuation and Centre for Exploration Targeting Plug-IN (CET).

Tawey M. D[1]* Udensi E. E[2] Adetona A. A[3] Alhassan U. D[4]

Geophysics Department, Federal University of Technology Minna
[4]a.usman@futminna.edu.ng
[3]tonabass@gmail.com
[2] eeudensi@yahoo.com
[1*]Corresponding author:**taweymam@gmail.com**

Abstract

A digitised aeromagnetic data covering part of central Nigeria was acquired and analysed with the aim of delineating mineralisation zones within the area using analytical signal, downward continuation, second vertical derivative and structural complexity analyses of the CET. From the analysis of analytical signal, the map reveals areas of low amplitude of 0.0024m in deep blue colour around south central portion of the area while the pinkish colour that dots all over the area has an amplitude of 0.2157m. This pinkish colouration concentrated around central portion to the western end of the study area. Application of downward continuation and second vertical derivative filters produces similar maps in which prospective zones of mineralisations were mapped out. These mineralisation zones were seen to be concentrated in areas with high magnetic signal of amplitude 0.2157m. Application of structural complexity analysis due to CET located deposits occurrence favourable zones that coincided with zones mapped out from SVD and downward continuation maps. Structural trends as revealed by CET Plug-IN are NE-SW, NW-SE, minor E-W and N-S trends.

Keywords: Mineralisation, Structural Complexity, Analytical Signal and CET

Introduction

Aeromagnetic maps usually reflect variations in the earth's magnetic field resulting from the underlying rocks' magnetic properties (e.g. magnetic susceptibilities). Sedimentary rocks have the lowest magnetic susceptibility, whereas metamorphic and acidic igneous rocks intermediate and basic igneous rocks have the highest magnetic susceptibility (Kearey *et al.*, 2002). As such,

large-scale aeromagnetic surveys have been used to locate faults, shear zones and fractures, such zones may serve as potential hosts for a variety of minerals and may be used as guidance for exploration of the epigenetic, stress-related mineralisation in the surrounding rocks (Paterson and Reeves, 1985) Magnetic anomalies are caused by magnetic minerals contained in rocks; such anomalies are usually caused by underlying basement (igneous and/or metamorphic) rocks or by igneous features such as intrusive plugs, dykes, sills, lava flows and volcanic centre (Gunn, 1997). Magnetic method is one of the best geophysical techniques used for determining depth to magnetic source bodies (and possibly sediment thickness) and delineating subsurface structures. Several articles have been published on the Nigerian basement complex's structural and tectonic framework and mineral constituent using magnetic data (Amigun, 2015a) also make use of magnetic method in the resource assessment of Ajabanoko iron ore deposit and his study demonstrated the potential value of this method to the problems of defining the structural setting, physical characteristic, ore geometry and economic potential of iron deposit as such, the present work focused on interpreting aeromagnetic data over part of central Nigeria with the aim of delineating mineralization zones and structural complexity which are usually host for minerals.

Location and extent of the study area

The study area is a rectangular block shape situated in the part of central Nigeria particularly in the northern Nigerian Basement Complex (Figure 1). It is bounded by latitudes $08^{0}30'$ N and $10^{0}30'$ N and longitudes $07^{0}00'$ E and $09^{0}00'$ E. The study area falls in three states namely Kaduna, Niger, Nasarawa and the Federal Capital Territory (FCT) (Figure 1).

Geology of the study area

The area is exclusively Basement and 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 philites granite gneiss and the Migmatite (Figure: 2)

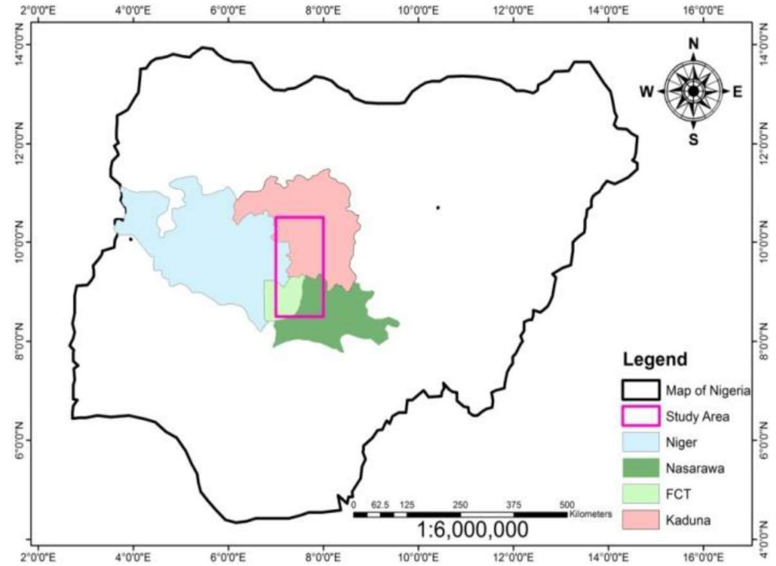

Figure: 1 Location of study area (Google, 2019)

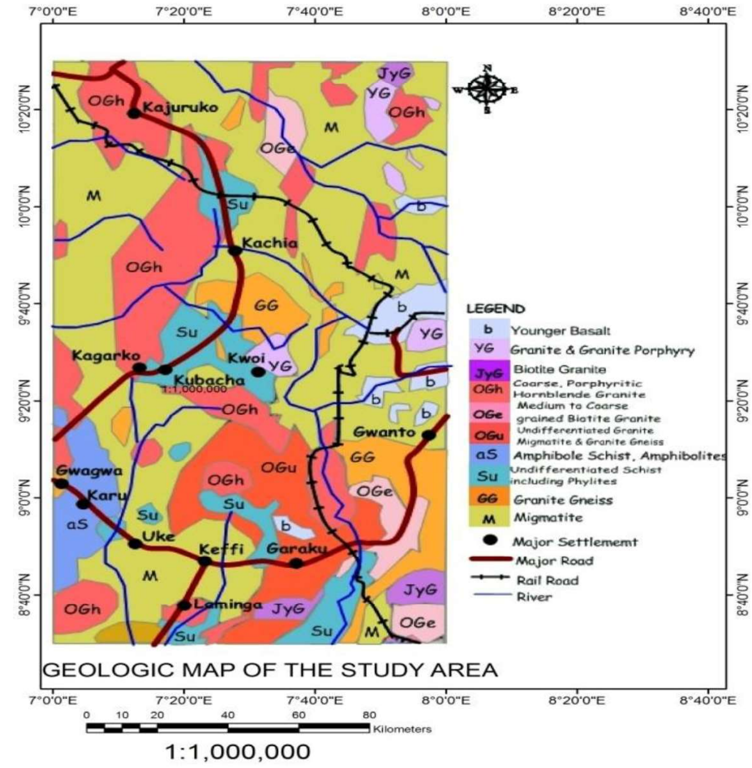

Figure: 2 Geologic map of the area (NGSA, 2006)

MATERIALS AND METHODS

Source of Aeromagnetic Data

The Aeromagnetic Data used for this study which was acquired from the Nigerian Geological Survey Agency (NGSA) Abuja is a new dataset that has been generated from the largest airborne geophysical survey ever undertaking in Nigeria, which is helping to position the country as an exciting destination for explorers. This survey took place between 2005 and 2009 and was financed by Nigerian Federal Government and the World Bank. The survey was conducted in two phases. Phase 1 was financed entirely by the Government of Nigeria. All of the airborne geophysical work data acquisition, processing and interpretation, was carried out by Fugro Airborne Surveys. Phase 1 was completed in September 2007 and included 826,000 line-km of magnetic and radiometric surveys flown at 500 m line spacing and 80 m terrain clearance; and 24,000 line-km of time-domain electromagnetic surveys flown at 500 m line spacing, flight line spacing of 100 meters and 80 m terrain clearance using Fugro's GENESIS EM system. Fugro was also tasked with interpretation of these data. The Phase 2, completed in August 2009, surveyed blocks not covered in Phase 1. It included 1,104,000 line-km of magnetic and radiometric surveys flown at 500 m line spacing and 80 m terrain clearance. These levels of survey are intensive: often a total of seven aircraft of three different types were active at one time. Phase 2 was supported by the World Bank as part of a major project known as the Sustainable Management for Mineral Resources Project.

Methods / Procedures

The procedures involved in this study include:

1. Production of Total Magnetic Intensity (TMI) map of the study area reduced to magnetic pole in color aggregate using Oasis Montaj software
2. Produce Analytical Signal map to locate outcropping areas and showcase places of probable mineralisation zones
3. Production of Downward Continuation map, since, the downward continuation filter when applied to potential field data brings the observation surface closer to the source therefore enhancing the responses from sources at depth from which mineralization zones can be mapped out
4. Computing the Second Vertical Derivative of the data and mapped out the mineralisation zones.
5. Complex structural analysis from Centre for Exploration Targeting (CET) to mapped out complex structural areas which could be probable areas of mineralization

Theories of the Methods

Reduction to Magnetic Pole

Reduction to the pole (RTP) is a standard part of magnetic data processing method, especially for large-scale mapping. RTP operation can transform a magnetic anomaly caused by an arbitrary source into the anomaly that the same source would produce if it is located at the pole and magnetised by induction only. Interpretation of magnetic data can further be helped by RTP in order to remove the influence of magnetic latitude on the anomalies which is significant for anomalies caused by crust. Reduction to the pole is the process of converting the magnetic field from magnetic latitude where the Earth's field is inclined, to the field at a magnetic pole, where the inducing field is vertical (LUO et al., 2010). When the Earth's field is inclined, magnetic anomalies due to induction have forms that are asymmetrically related to their sources, but when the inducing field is vertical, the induced anomalies are directly over their sources (Milligan & Gunn, 1997). Fourier transform is applied to transform RTP from the space domain into the wavenumber domain. The RTP operation in wavenumber domain can be expressed as

$$A_P(u,v) = \frac{A_C A_p(u,v)}{(sinI + icosIcos(D-\theta))^2} \qquad 1$$

Where $A_P(u,v)$ be the Fourier Transform of these observed magnetic data, $A_c(u,v)$be the Fourier Transform of the vertical magnetic field, I and D is the inclination and declination of core field, (u,v) is the wavenumber corresponding to the (x, y) directions respectively and $\theta = \arctan\left(\frac{u}{v}\right)$ (LUO *et al.,* 2010). Reduction-to-the-pole (RTP) is a useful and effective operation designed to transform a total magnetic intensity (TMI) anomaly caused by an arbitrary source into the anomaly that this same source would produce if it were located at the pole and magnetized by induction only (Li, 2008).

Analytical method

Analytical signal of TMI has much lower sensitivity to the inclination of the geomagnetic field than the original TMI data, and provides a means to analyses low latitude magnetic fields without the concerns of the RTP operator. Analytical signal is a popular gradient enhancement, which is related to magnetic fields by the derivatives. Roest *et al.,* (1992), showed that the amplitude of the analytic signal can be derived from the three orthogonal gradient of the total magnetic field using the expression:

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

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, it is extremely interesting in the context of interpretation, as it is completely independent of the direction of magnetisation and the direction of the Earth's field (Milligan & Gunn, 1997). This means that all bodies with the same geometry have the same analytic signal. Analytic signal maps and images are useful as a type of reduction to the pole, as they are not subject to the instability that occurs in transformations of magnetic fields from low magnetic latitudes. They also define source positions regardless of any remnant magnetization in the sources (Milligan & Gunn, 1997).

Upward/Downward Continuation of the field

The amplitude of a magnetic field above a source varies with elevation as an exponential function of wavelength. This relationship can be readily exploited with FFT filters to re-compute the field at a higher elevation (upward continuation) or lower elevation (downward continuation) (Foss, 2011). A potential field measured on a given observation plane at a constant height can be recalculated as though the observations were made on a different plane, either at higher or lower elevation. As described by Gunn (1997), the process has a frequency response of $e^{-h}(u^2 + v^2)^{\frac{1}{2}}$ (where h is elevation). This means that upward continuation smooth out high-frequency anomalies relative to low-frequency anomalies. The process can be useful for suppressing the effects of shallow anomalies when detail on deeper anomalies is required. Downward continuation on the other hand sharpens the effects of shallow anomalies (enhances high frequencies) by bringing them closer to the plane of observation. For upward continuation (where z is positive downward) (Telford et al., 1990)

$$f(x, y, -h) = \frac{h}{2x} \iint \frac{F(x,y,0)dxdy}{\{(x-x')+(y-y')+h^2\}^{\frac{1}{2}}} \qquad 3$$

Where F$(x, y, -h)$= Total field at the point p$(x', y' - h)$ above the surface of which

F$(x, y, 0)$ is known h = elevation above the surface

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:

$$\frac{1}{n}\left[(U^2+V^2)^{\frac{1}{2}}\right]^n \qquad 4$$

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 these operations shows that the process enhances high frequencies relative to low frequencies, and this property is the basis for the application of the derivative process which eliminates long-wavelength regional effects and resolves the effects of adjacent anomalies. The second vertical derivative has even more resolving power than the first vertical derivative, but its application requires high quality data as its greater enhancement of high frequencies results in greater enhancement of noise. Higher orders of derivatives are virtually never used to produce interpretation products (Gunn et al., 1997a).

Complex structural analysis

Centre for Exploration Targeting (CET) is a suite of algorithms which provides functionalities for enhancement, lineament detection and structural complexity analysis of potential field data (Holden et al. 2008; Core et al. 2009). This technique automatically delineate lineaments and identify promising areas of ore deposits via outlining regions of convergence and also divergence of structural elements using several statistical steps that include texture analysis, lineation delineation and Vectorisation and complexity analysis to generate contact occurrence density map. This method identifies magnetic discontinuities using combination of texture analysis and bilateral symmetric feature detection Geosoft, (2012). It then identifies regions of discontinuity and analyses structural associations to locate crossing, junctions, and change of direction of strike. Finally, by measuring the density of the structural contacts and the diversity in the strike structures as a heat map, it facilitates picking the areas that are perceived to be prospective. Nonetheless, since the workflow is directly applied to gridded datasets, any geophysical data sensitive to the geologic structure could be subjected to this to delineate ridges or edges of the geologic structure and when using magnetic data in this process, it is highly recommended to pole reduce the data first so that the anomalies are shifted over their causative structures (Geosoft, 2012).

RESULTS AND DISCUSSIONS

Total Magnetic Intensity TMI/TMI Reduced to Magnetic pole

From total magnetic intensity map (Figure: 3A), the magnetic intensity of the study area ranges from 32950.05nT minimum to 33087.93nT maximum. The area is marked by both high and low magnetic closures, which could be attributed to Factors such as degree of rock strikes, difference in rock lithology of the area, difference in rock magnetic susceptibility of the area, and differences in the depth at which these rocks occur. Areas around the southern part and from the center to the western end of the area are mark with high magnetic closure attributed to the exposed basement nature of the environment while the long wavelength anomaly at the south central portion of the area is attributed to areas that are covered with thick layer of sediment (Figure 3A). To place the anomalies from the residual magnetic field directly over the magnetic field resulting from causative rocks that bring about these anomalies, the TMI grid was transformed into reduction to the pole (RTP) grid using the 2D-FFT filter in Geosoft software to make easy the interpretation of the magnetic data set. The reduction to pole magnetic anomaly image (Figure 3B) depicts both low and high frequencies coming from the magnetised rocks in the region. These strong anomalies with high frequencies are observed directly at the east of the area through the central portion to the western end of the area. The map of RTP also helps to sharpen the contacts between the magnetic high and low patterns and also emphasized on anomalously magnetic susceptible zones possibly coming from deeper sources.

Analytic Signal

The most significant feature of the analytical signal is that it does not dependent on the magnetization field of the source rock. The mineral deposits with high concentrations always show high analytical signal amplitudes. This shows that analytical signal amplitude depends on the magnetizing amplitude of the causative body (Nabighian, 1972; Roest and Pilkington, 1993). High analytical signal amplitudes are recorded which could be areas of large mineral deposits and a closer look at Analytic signal map (Figure: 4), the amplitudes ranges from 0.024m around south central portion of the study area and extreme north central portion of the area to 0.2157m.Thus, areas around central portion of the study area to the western end of the map also have the highest amplitude. They are areas of freshly intruding rocks as such are areas expected to be zones of mineralisation. Areas around north western end part of the study area, southern part and eastern part of the study area also have some dots of high amplitude anomalies as such are also expected areas of mineralisation. With the application of this filter, structures with trend NE-SW and NW-SE were mapped were also out in black strikes (Figure: 4).

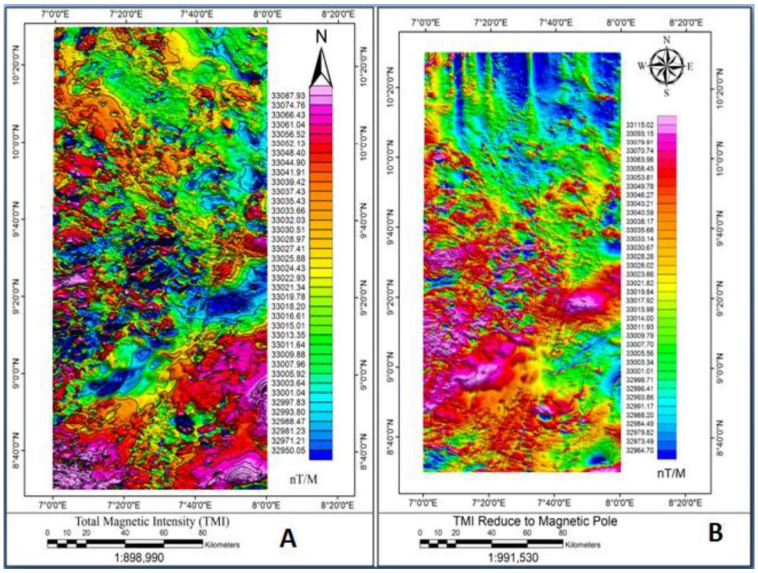

Figure: 3 TMI and TMI Reduce to Pole

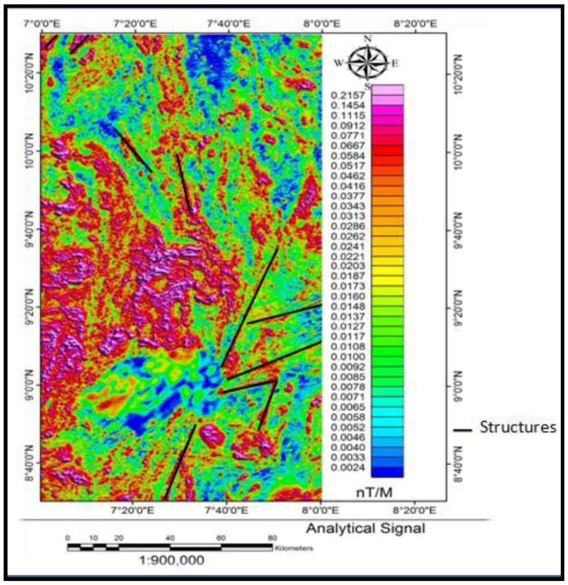

Figure: 4 Analytical Signal Map

Downward Continuation

The application of downward continuation filter enhanced responses from shallow depth sources by effectively bringing the plane of measurement closer to the source. When this filter was applied to the data, produces (Figure 5.A). From the map produced (Figure 5.A), mineralization zones were inferred and mapped out by labeling. These are areas around A, B, C, D, E, F, G and H in (Figure 5A).

Second Vertical Derivative

Second vertical derivative filter was applied to enhance subtle anomalies while reducing regional trends. This filter is considered most useful for defining the boundaries of anomalies and for amplifying fault trends. The SVD map (Figure: 5B) reveals the boundaries of those shallow anomalies clearly. This made it possible to delineate the various mineralization zones with some

Structures mapped out in black strikes. Just as the case of downward continuation map (Figure 5A), Figure 5 B is very similar to the downward continuation map and the boundaries of anomalies (mineralization zones) are represented by areas around A, B, C, D, E, F, G and H in (Figure 5B).

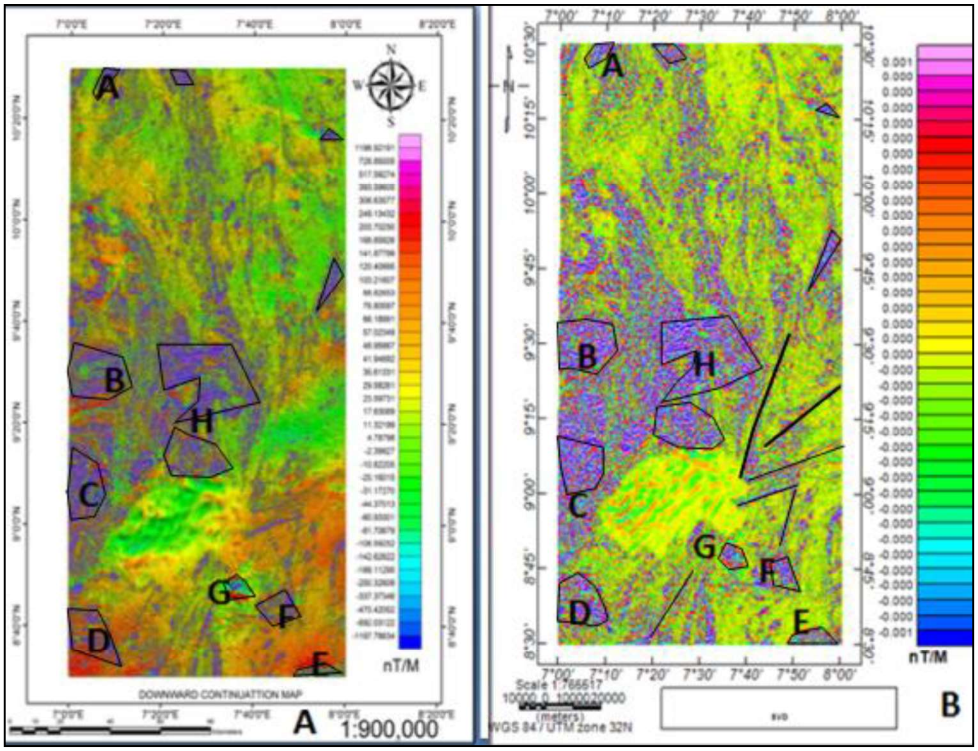

Figure: 5 Downward Continuations and Second Vertical Derivative Map

Structural Complexity Map and Interpretation

The structural complexity analysis is used here to locate deposit occurrence favourability. Texture Analysis was selected from CET window followed by a displayed Standard Deviation dialog. A running window generated a measure of randomness of the texture and two statistical methods were supplied, these are the entropy method and the standard deviation but the standard deviation provides a smoother representation of the degree of randomness that overcomes the inherent noise in the data. For the input filename (grid), pole reduced magnetic grid was selected, for the output filename (grid), standard deviation was entered and the map produced (Figure: 6A). This map is very similar to the Analytical signal map produced (Figure: 4). Here, the structures are seen beginning to align themselves and the application of phase symmetry produces the map in (Figure: 6B) where structures were singled out.

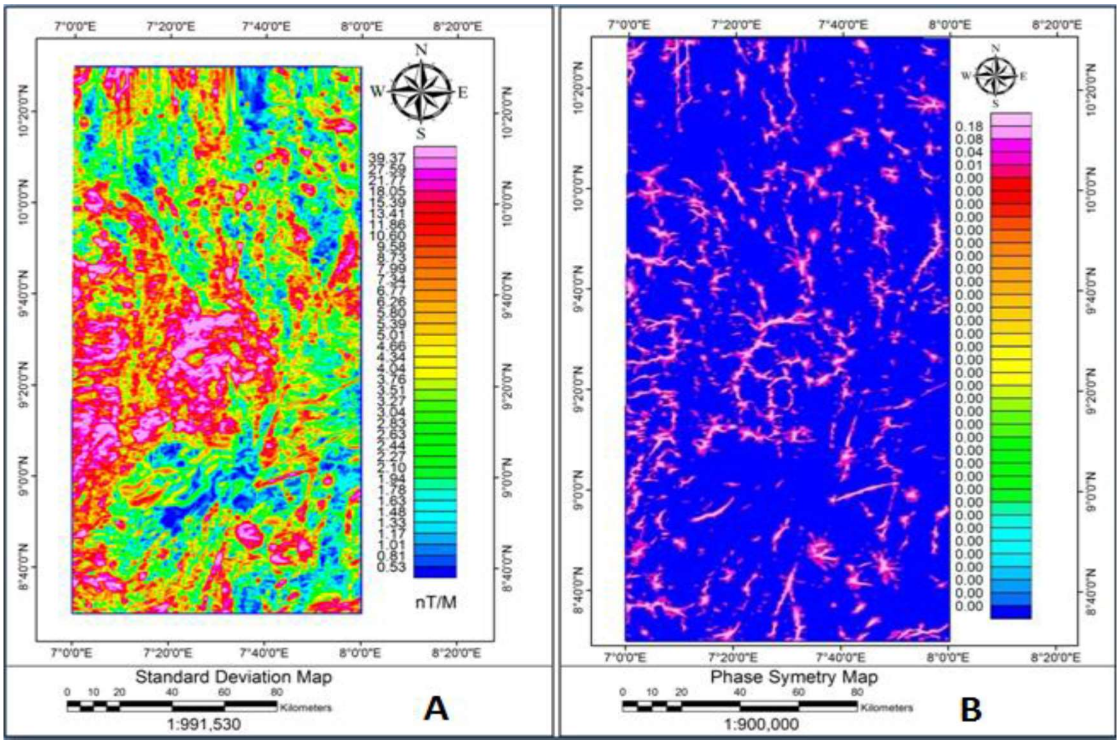

Figure: 6 Standard Deviation and Phase Symmetry Maps

While application of skeletal to vectors PLUG-IN produce the map (Figure: 7A). These structures are overlay on the orientation entropy map (Figure: 7B). The orientation entropy map picks only the localized junctions where the structures bend or changes direction as indicated in the map. The generated map (Figure: 7B) indicated areas of junctions of high densities lineament overlaid by the structures in (Figure: 7A). These are areas favourable for hosting minerals as these areas on this map when compared with downward continuation and second vertical derivative map (Figure: 5A and 5B) both have these mineralization zones in similar portions on the maps. These are areas favourable for hosting deposits of interest and could be further explore in more detail.

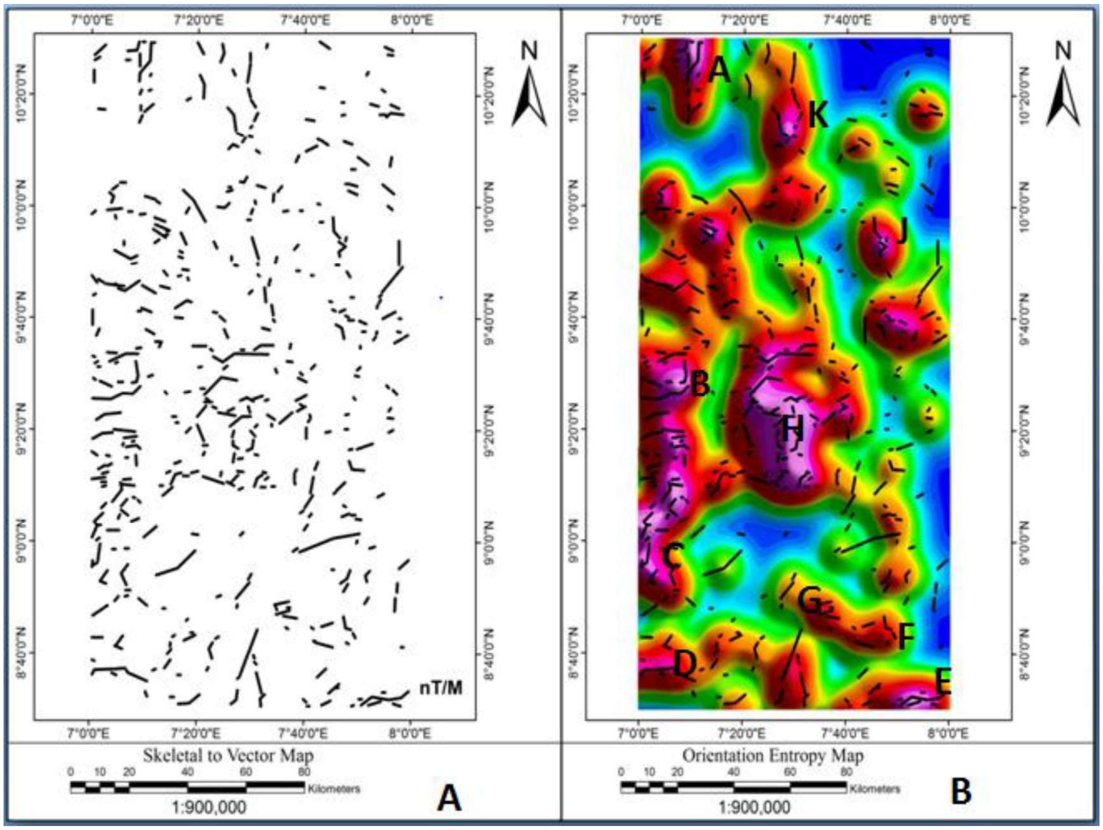

Figure 7Skeletal to Vectors and Orientation Entropy Maps

Conclusions

From the analysis of analytic signal (Figure: 4), areas of high amplitude were observed which are envisage to be areas of probable large mineral deposit having amplitude of 0.2157m from the central portion of the map toward the western end of the study area. Anomalies of the same amplitude dot other parts of the area. The map also revealed structures that were mapped out having NW-SE and NE-SW trends. The second vertical derivative and downward continuation maps (Figure: 5A and 5B) reveals boundaries of mineralisation zones that were mapped out and labeled A, B, C, D, E, F, G and H within the study area while the structural complexity analysis generated a map (Figure: 7A and 7B) that picks or indicated areas of junctions of high density overlayed by the structures produced. These are areas favourable for hosting minerals as areas of high structural densities when compared with SVD and downward continuation maps (Figure: 5 A and B) confirmed both three maps to have the mineralization zones on a similar portions of the individual three maps. Structural maps produce from CET analysis (Figure: 7 A) reveals the area having structures of dominant NE-SW and NW-SE trends.

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