DELINEATION OF MINERALIZATION ZONES USING AEROMAGNETIC DATA IN PARTS OF NORTH CENTRAL, NIGERIA

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ABSTRACT

Exploration of solid minerals would have been the best source of income generation for Nigerians, but attention shifted totally to mining of crude oil by successive administrations due to the lure of easier profits from oil production. Naturally, the region where the study area is located is blessed enormously with different varieties of solid minerals that are economically and technically viable for exploitation. But, most of these solid minerals are yet to be exploited and so far, the exact locations of these minerals in the subsurface are unknown. To identify and map out lineaments (geological structures) hosting these minerals, a study was carried out with the aim of delineating mineralisation zones using Aeromagnetic Data. The study site covers a total surface area of about 18,150 km^2, geologically, 75% of the total landmass of the area is underlain by Precambrian rocks of the Nigeria Basement complex while the remaining 25% part is occupied by the Cretaceous Sedimentary rocks belonging to Bida Basin. Six different aeromagnetic data sheets were grid knitted into a unified sheet that represents the study area Total Magnetic Intensity (TMI) map using the Geosoft® Oasis Montaj™ software package. For the vital purpose of accurate positioning of the anomalies, the TMI was reduced to magnetic equator. Visual interpretation of Residual Magnetic Intensity (RMI) map revealed that the high and low magnetic anomalies are surrounded by high gradient zones trending in the E-W directions. Furthermore, the filtering techniques used in enhancing identification and mapping of lineaments (shallow geological structures) that accommodates solid mineral deposits are First Vertical Derivative (FVD), Tilt Derivative and CET. The produced maps of each techniques used, agrees with each other by revealing the trends of the lineaments that could possibly host solid minerals. Source Parameter Imaging (SPI) also revealed the average depths of geological structures. Basic dykes and quartz veins are the surface manifestations of NE-SW trend in Basement complex. The revealed lineaments may be inferred to indicate a complex interplay of tectonic activities due to multiple deformational episodes in the area. This may be likely mineralisation zones.

Keywords: Solid Mineral, Lineaments, Exploitation, Aeromagnetic data.

INTRODUCTION

The act of dabbling into exploration studies most times is purposely for the search of naturally occurring solid minerals that are economically and technically viable for exploitation. Solid minerals are vital solid inorganic substances with definite structures found mostly beneath the Earth surface. If these vital substances were to be explored and exploited using appropriate geophysical survey techniques, obviously, it would serve as an additional source of income to the entire country. This is because the vastness of each of the different imperative substances explored is capable of improving and increasing the region's financial streams as well as lessening the growing population of unemployed citizens living within such locality. Furthermore, interested foreign investors would also negotiate their way into such locality to invest on the available vital solid substances viable for exploitation. Utilization of vital solid inorganic substances (solid minerals) would have been the best source of income generation for Nigerians, but attention shifted totally to mining of crude oil due to the lure of easier profits from oil production. Although, the Nigeria petroleum sector has contributed hugely to the nation's economy, and up till date, it is the most important source of financial income. Due to the recent downward trend of oil price and its impact on the nation's revenue, the need for Nigeria to protect herself by diversifying her revenue's stream becomes very important. More so, if adequate attention and proper management is given to solid mineral sector (exploration of solid minerals), obviously, the exploration of any of the discovered solid mineral would contribute immensely to the national wealth and also serve as an extra socio-economic benefit for the entire country. Naturally, the region where the study area is located is blessed enormously with different varieties of solid minerals that are economically and technically viable for exploration. But, most of these minerals are yet to be explored and so far, the exact locations of these vital substances are unknown. In order to understand the structural dynamics and economic mineral potential of the area, aeromagnetic survey technique was employed due to its cost-effectiveness in this study to reveal the concealed geological structures (lineaments) probably hosting certain anomalous solid mineral deposits in the area. Besides, this technique is an important tool used in delineating the regional geology of buried basement terrain (Omowumi, 2017). Current advances in technology have significantly augmented the accuracy and resolution of aeromagnetic techniques so as to provide useful improved information on lithology and geological structures. Regional exploration of structurally controlled mineralization usually requires geophysical methods that have the capacity to delineate subsurface structures that may indicate the presence of these mineral deposits. For this reason, Aeromagnetic data sets was utilized in this study to delineate geological structures (lineaments) associated with mineralization zone. This is the first of a suite of exploration activities in the study site designed to map optimal targets for the investigation of different economic mineral deposits. Though, Previous geophysical and geological studies have revealed that the region (North-Central) can be a potential site for solid mineral prospects (Adewumi and Salako 2017; Ejepu *et al*., 2018).

LOCATION AND GEOLOGY OF THE STUDY AREA

The study site is located in North-Central part of Nigeria. The area cut across two states (Niger and Kaduna) including parts of the Federal Capital Territory (FCT). The study site is bounded by Latitudes 9° 00′ N and 10° 00′ N and Longitudes 6° 00′ Eand 7° 30′ E coordinates with projection coordinates referenced to the World Geographic System (WGS) 84, covers a total surface area of 18,150 km^2 (Figure 1). Geologically, 75% of the total landmass of the study site predominately underlain by the basement rocks falls within the Northwestern portion of the Precambrian Basement Complex of Nigeria (Figure 2).

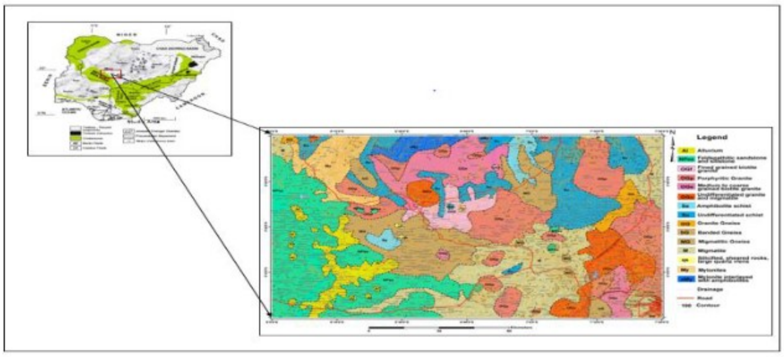

Figure 1: Location of the Study Area

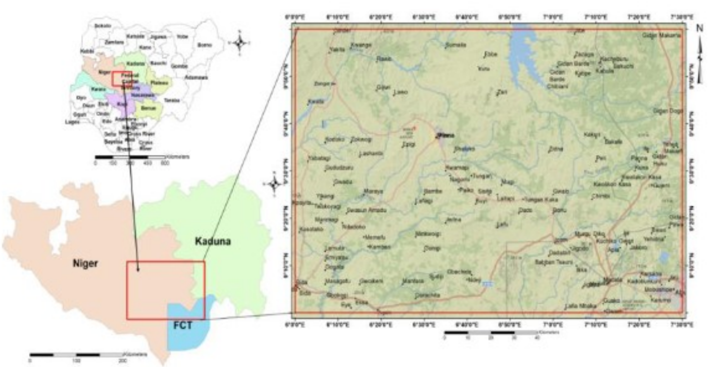

Figure 2: Geological map of the study site (adapted from Nigeria geological survey agency (NGSA2009): Top left is a sketch geological map of Nigeria showing the study area (Obaje 2009)

The study site which is also part of the Precambrian Basement Complex of Nigeria is between Archean to early Proterozoic in age (Obaje 2009).The Basement Complex rocks of Nigeria is part of the African crystalline shield which occurs within the Pan African mobile belt that lies between the West African and Congo Cratons and South of the Tuareg Shield which were affected by the Pan-African orogeny (Oyawoye 1972). Based on tectono-stratigraphic separation, (Adekoya *et al*., 2003) indicated that the part of the study site is composed of the Gneiss-Migmatite Quarzite Complex, the schist belts which are low to medium grade supracrustal and meta-igneous rocks, the Pan African Granites (older granites and associated granitoids) and Minor felsic and mafic intrusive. The noticeable lithologies on the basement complex part of the geologic map of the study area (Figure 2) are: biotite rich granites, porphyritic granite, amphibolites schist, migmatite, quartz veins and mylonites. The remaining 25% part of the study site is occupied by the Cretaceous Sedimentary rocks belonging to the Bida Basin (Figure 2). Bida Basin is a gently down-warped trough whose genesis may be closely connected with the Santonian orogenic movement of south-eastern Nigeria and the Benue valley (Obaje *et al*., 2011). This portion that falls within Bida Basin was initially formed as a result of series of tectonics and repetitive sedimentation in the Cretaceous time when South American continent was separated from Africa and the opening of the South Atlantic Ocean (Cyril 2019). The portion contains a north-west trending belt of Upper Cretaceous sedimentary rocks mostly siltstones and sandstones deposited as a result of block faulting, basement fragmentation, subsidence, rifting and drifting consequent to the Cretaceous opening of the South Atlantic Ocean Obaje 2009). Alluvium deposits which could be sand, salt, clay, gravel or even organic matter were spotted in the sedimentary part of the geologic map of the study site.

MATERIALS AND METHODS OF STUDY

Materials

1. Aeromagnetic data sets: the data were made available in form of six Total Magnetic Intensity (TMI) grids, each published in the form of ½ degrees by ½ degrees maps on a scale of 1:100,000, and each designated as sheet 163 (Zungeru), 164 (Minna), 165 (Bishini), 184 (Bida), 185 (Paiko), and 186 (Abuja) respectively
2. Geology map covering the study area

   The software packages integrated are:-
3. Geosoft® Oasis Montaj™ version 8.4
4. RockWorks17.

METHODOLOGY

Data Acquisition

The Federal Government (FG) of Nigeria organized a nationwide airborne geophysical survey exercise with the ultimate goal of providing high-quality geosciences data sets that would facilitate the exploration of solid mineral. The airborne geophysical survey exercise was executed between 2005 and 2009 by Fugro Airborne Surveys (FUGRO) under the supervision of the Nigerian Geological Survey Agency (NGSA). The obtained aeromagnetic data sets in form of TMI grids utilised in this research were acquired from the Nigerian Geological Survey Agency (NGSA). The respective TMI grids were windowed out of the corresponding gridded TMI maps amassed after the nationwide airborne geophysical survey exercise. Based on the information provided by the NGSA, the survey exercise was executed with an aircraft with fixed wings (Cessna) covering a total of 250-290 kilometres per hour (Km/h) with a flight spacing of 500 metres and a sensor mean terrain clearance of 80 metres. The aircraft had a magnetometer mounted on its wings. The flight line direction was NW-SE (135 degrees) with a tie-line spacing of five kilometres and a tie-line direction of NE-SW (45 degrees). A high-sensitivity magnetometer recorded the magnetic data at an interval of 0.1 second, a grid mesh size of 50 meters were applied in the World Geodetic System of 1984 (WGS 84) within UTM Zone 32 North and with the Clark 1880/Arc 1960 coordinate system (source: www.ngsa.gov.ng). However, the geomagnetic total (global) field was removed from each of the grids using the International Geomagnetic Reference Field (IGRF).

Data Processing

Processing of aeromagnetic data involves the use of appropriate software packages that aids sequential processes of editing, gridding routine, and the removal of Earth's background magnetic field (Wemegah *et al*., 2015). Though, the choice of gridding routines applied to the magnetic data set is to visually enhance certain features of interest. The six (6) TMI grids each designated as sheet 163 (Zungeru), 164 (Minna), 165 (Bishini), 184 (Bida), 185 (Paiko), and 186 (Abuja) covering the study area were grid knitted into a unified sheet that represents the TMI map of the study area using the Geosoft® Oasis Montaj™ version 8.4 software package. The unified TMI map coordinates were re-projected from projected (x, y) coordinates to geographic (longitude and latitude) coordinates system and re-gridded using the minimum curvature gridding technique which is the smoothest likely surface that would fit the given data values (Briggs 1974). The procedure was essential because the coordinates of the new TMI map must correspond to the actual coordinates of the study site. Thus, the new map denotes the real

TMI map of the study area (Figure 3). Subsequently, further numerical processes of the data were achieved using Geosoft® Oasis Montaj™ software package. In order to correct the effect of low latitude anomaly shift inherent problem and to symmetrically Centre anomalous bodies (structures) above their corresponding causative bodies since the study site is closer to the equator, the Reduction to Magnetic Equator (RTE) filter was applied to the real TMI grid with -6.7 and -1.1 representing the inclination and declination values respectively of the geomagnetic field parameters and the end result lead to the production of RTE-TMI map (figure 4) of the study area. The RMI-TMI map of the study area was adopted as the new processed map for subsequent data analysis and interpretations. In order to achieve the main purpose of this study, certain filtering techniques such as First Vertical Derivative (FVD), Tilt Derivative, Centre for Exploration Targeting (CET), Analytic signal and Source Parameter Imaging (SPI) were applied with the objectives of identifying, mapping and depth estimation of hidden geological structures (lineaments) probably hosting anomalous deposits of solid minerals.

Results and Interpretation

In an attempt to deduce variation of magnetic response of different geologic features presumed to be anomalous bodies with different patterns, orientations, frequencies and amplitudes with respect to their depths and locations with high and low magnetic susceptibilities, the interpretation of the acquired aeromagnetic data sets covering the study was executed following a qualitative and quantitative interpretation approach. Thereafter, the data were enhanced and analyzed for subsequent interpretation. The qualitative interpretation approach was executed by visually inspecting the different magnetic anomaly maps produced as a result of employing two different filtering techniques. The qualitative interpretation approach visually describes the displayed consequences of the major geologic features that are mostly shallow subsurface structures assumed to be lineaments (faults, fractures, folds, joints or even contact zones) perhaps hosting mineral deposits and suspected mineralization zones (geological formations) that originate the evident anomalies (Emmanuel *et al*., 2018). Besides, it involves the measurement of total magnetic intensity (nT) via application of mathematical filters that view data meant to enhance the anomalies of interest. Likewise, quantitative interpretation approach entails making numerical estimates of the depth of the sources of anomalies of interest. In order to delineate and distinguish the lithologies associated with geologic structures (lineaments) perhaps hosting vital mineral deposits in the study area, the resulted maps created base on the qualitative interpretation approach includes:

Total Magnetic Intensity (TMI) Anomaly Map of the Study Area

The TMI anomaly map (Figure 3) of the study area is a pictorial representation of concealed magnetic features associated geologic structures displayed in different colour aggregate. The TMI anomaly map (Figure 4.1) reveals the distribution different low/negative (light to dark blue colours) and different high/positive (mengata to red colours) magnetic signatures (anomalies) which are attributed to factors like difference in magnetic susceptibility, lithology and variation in depth. The amplitude (intensities) of the magnetic anomalies ranges from a minimum value of -1156.12 nT to a maximum value of 500.32 nT. Towards the north-west down to the southern part of the map (Figure 4.1), there are dominant high concentrations of positive features with oblong shape. The amplitude of the magnetic anomalies within that terrain suggests the presence of highly magnetized intrusive bodies.

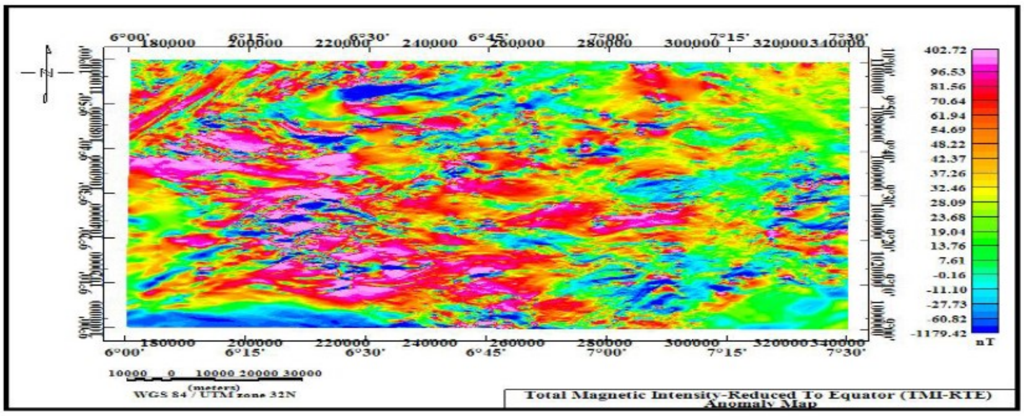

Figure 3: Total Magnetic Intensity (TMI) Anomaly Map of the Study Area. Colour Bar at the Right Side Signifies the Intensities of the Magnetic Anomalies Measured in Nanotesla (nT)

Total Magnetic Intensity-Reduced to Equator (TMI-RTE) Anomaly Map of the Study Area

The TMI anomaly map (Figure 3) of the study area was transformed into TMI-RTE anomaly map (Figure 4) of the study area using the Reduce-To-Equator filter. The essence of the transformation is to centre the peak of the magnetic anomalies directly on the target (that is, make anomalies appear horizontally above their source bodies (causative bodies)) since the study area falls within low magnetic latitudes. Though, the TMI-RTE anomaly map (Figure 4) demonstrates no significant modification in its trend of the original magnetic anomalies when compared to the TMI anomaly map (Figure 3) of the study area, instead, it (Figure 4) shows that the maximum and minimum intensity values of the distributed magnetic anomalies have reduced to 402.72 nT and increased to −1179.01 nT which is an indication that the magnetic anomalies have shifted slightly upward (to the north) to their exact position. A general outlook on the TMI-RTE anomaly map (Figure 4.2) shows that the magnetic anomalies correlates weakly with the geologic signatures on the sedimentary terrain and basement terrain when compared with the geological map of the study area. However, the high (positive) concentration of magnetic anomalies noticed in very low magnetic region are suspected to be intrusion of outcrops of cretaceous rocks (sandstones and siltstone) within that terrain. Meanwhile, the magnetic anomalies noticed on the high magnetic region are suspected to be quartz, amphibolites schist, feldspar, granite gneisis or migmatite (basement terrain). Since, the TMI-RTE map (Figure 4.) of the study area was processed to transform and enhance magnetic anomalies presumed to be shallow seated geologic structures perhaps hosting mineral deposits, hence, the TMI-RTE anomaly map (Figure 4) of the study is adopted as the real grid map of interest for subsequent interpretation.

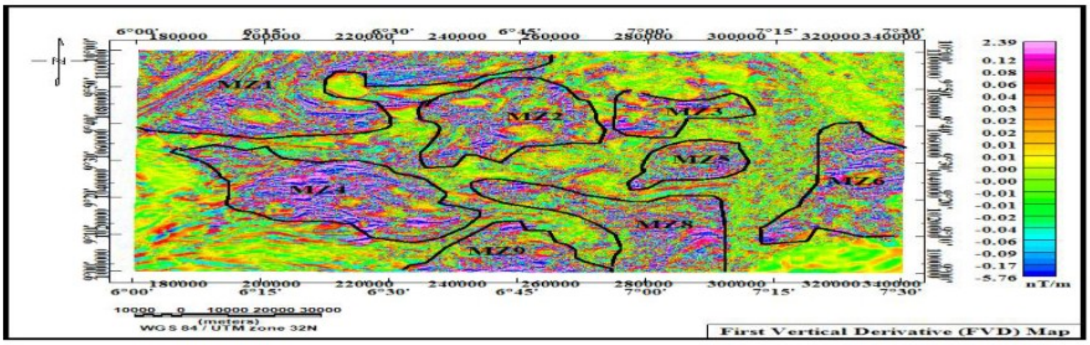

Figure 5a: First Vertical Derivative (FVD) Map of the Study Area. Colour Bar at the Right Side Signifies the Intensities of the Magnetic Anomalies Measured in Nanotesla per Metre (nT/m)

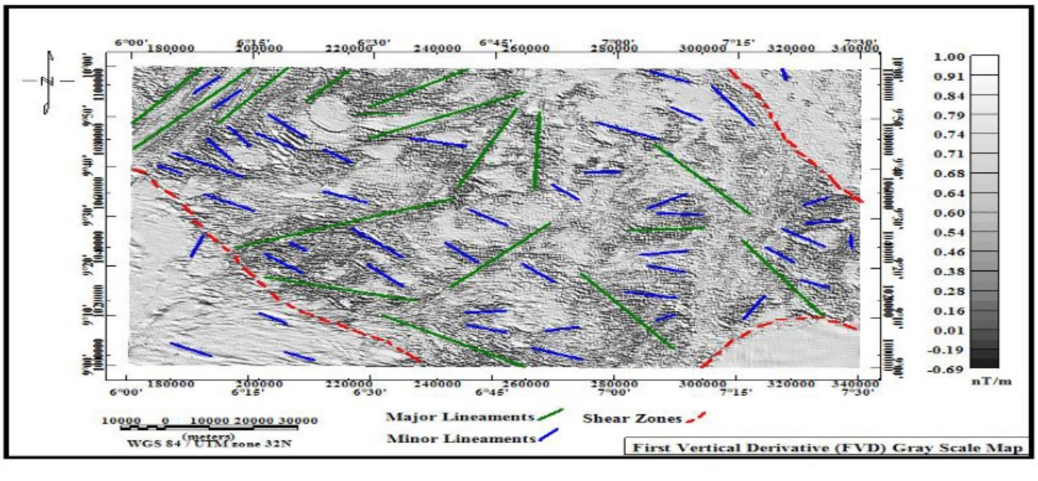

Figure 5b: First Vertical Derivative (FVD) Map of Study Area in Gray Scale with Mapped Geologic Structures (Lineaments). Colour Bar at the Right Side Signifies the Intensities of the Magnetic Anomalies Measured in Nanotesla per Metre (nT/m)

Tilt-angle Derivative (TD) and Its Total Horizontal Derivative (THD-TD)

The TD maps (Figure 6a) of the study area was obtained following the application tilt derivative filter on the TMI-RTE grid of the study. The TD map (Figure 6a) displays the geologic features assumed to faults, fractures or contacts which are depicted as magnetic lineaments perhaps playing a host to vital mineral deposits in the study area. Thus, it shows the horizontal location with comprehensive edges. The zero contour line (black line) in the TD map is the position of sudden changes in magnetic susceptibilities between high (positive) and low (negative) magnetic anomalies which are particularly at the sharp gradient. So, the zero contour lines represent the contact boundary of magnetic sources. Besides, the map shows the cumulative characteristic geologic features which are materialized by the different trends most likely reflecting the existence of ancient tectonic activities in the area. A total horizontal derivative filter was applied to the tilt derivative of the TMI-RTE grid to generate the THD-TR anomaly map (Figure 5b). The map (Figure 6b) shows the preserved the amplitude enhancement by its ability to define edges of well-defined maxima. So, the amplitude of the THDR_TDR is related to the reciprocity of the depth to the top of the source. The tilt angle overcomes the problem of the shallow and deep sources by dealing with the ratio of the vertical derivative to the horizontal derivative; the tilt derivative will be relatively insensitive to the depth of the source and should resolve shallow and deep sources equally. A total horizontal derivative filter was applied to the tilt derivative of the TMI-RTE grid to generate the THD-TR anomaly map (Figure 4.5b). The map (Figure 4.6b) shows the preserved the amplitude enhancement by its ability to define edges of well-defined maxima. So, the amplitude of the THDR_TDR is related to the reciprocity of the depth to the top of the source. The tilt angle overcomes the problem of the shallow and deep sources by dealing with the ratio of the vertical derivative to the horizontal derivative; the tilt derivative will be relatively insensitive to the depth of the source and should resolve shallow and deep sources equally.

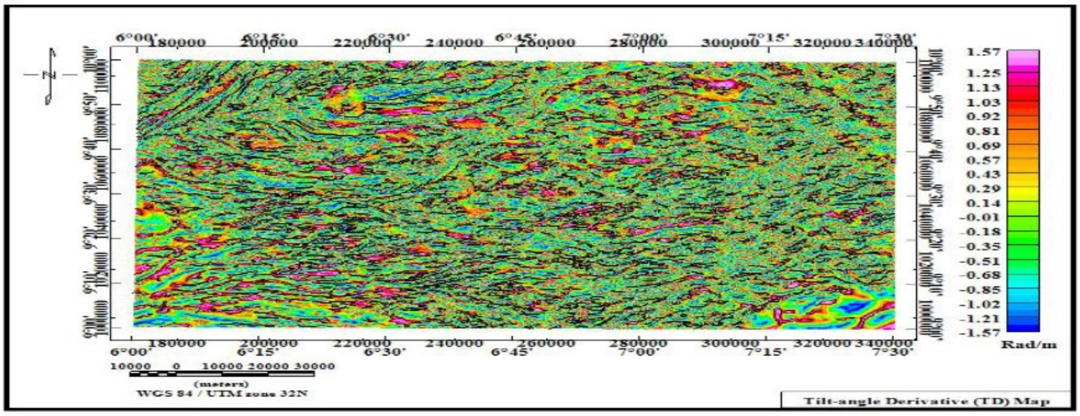

Figure 6a: Tilt-angle Derivative (TD) Map of Study Area Mapped Geologic Structures (Lineaments). Colour Bar at the Right Side Signifies the Intensities of the Magnetic Anomalies Measured in Radian per Distance (Rad/m)

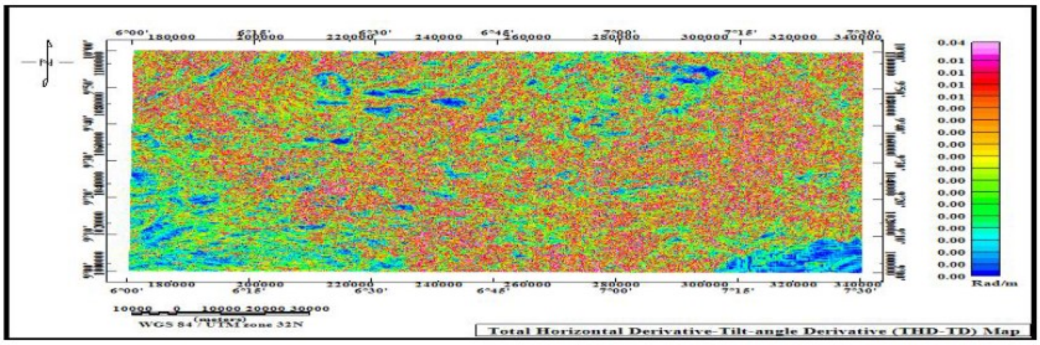

Figure 6b: Total Horizontal Derivative-Tilt-angle Derivative (THD-TD) Map of Study Area. Colour Bar at the Right Side Signifies the Intensities of the Magnetic Anomalies Measured in Radian per Distance (Rad/m)

Analytic Signal Amplitude (ASA)

In order to be acquainted with the source positions of the magnetic anomalies regardless of direction of the sources effects predominantly connected with the TMI-RTE grid, Analytical Signal (AS) map (Figure 6a) was produced following the application of analytic signal filter on the TMI-RTE grid. The AS map (Figure 6b) highlights the variation of the enhanced edges and texture of the magnetic bodies corresponding lineaments (faults and fractures) possibly harbouring deposits of vital minerals in the study area. The displayed magnetic zones with extremely high analytical signal amplitude ranged between 0.310 m to 5.580 m are the prospective depth of magnetic lineaments and exact locations of mineralisation zones in the area. However, the most significant concentrations of mineral deposits in an area are associated with high analytical signal amplitudes (Reeves *et al*., 1998). Comparing AS map (Figure 6a) with FVD map (Figure 5a) of the study area, shows that the enhanced edges of the magnetic bodies within the assumed mineralisation zones are discernible (clearly visible) and are considered to delineate lithological boundaries that produce the responses.

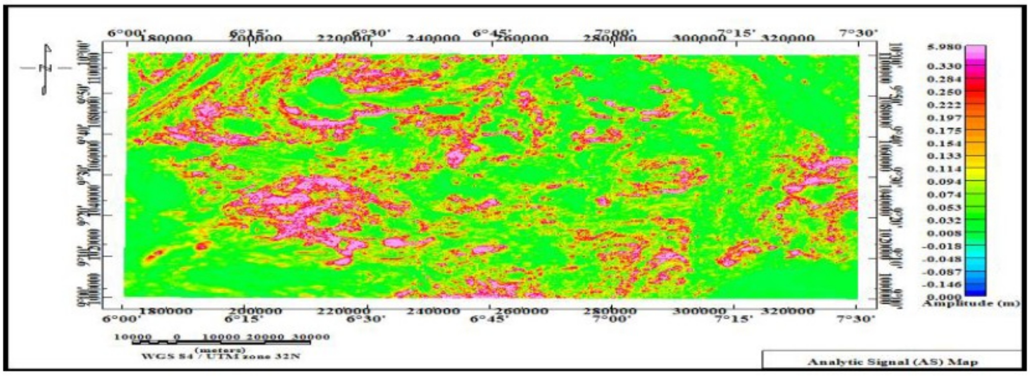

Figure 7: Analytical Signal (AS) Map of the Study Area. Colour Bar at the Right Side Signifies the Amplitude of the Magnetic Anomalies Measured in Metres (m)

Centre for Exploration Targeting (CET) Grid Analysis

The CET grid analysis approach was performed in order to identify lineaments enclosed within the TMI-RTE grid following the by-product maps created via standard deviation which estimates magnetic variations, phase symmetry which separate laterally continuous lines and afterwards, the end result lineaments enhanced by suppressing noise and background signals using an amplitude thresholding. The essence of the approach was to create a Vectorisation lineament map (Figure 6). The map (Figure 6) discloses lineament features equivalent to structures like faults, fractures and lithological boundaries. On a general outlook on (Figure 6), the lineaments displayed on Basement Complex part of study area are extremely distorted compare to the ones displayed on the Sedimentary terrain. Besides, it shows that the majority of the prominent lineaments are trending towards the E-W directions while the minor ones are trending in the NE-SW, and N-S directions.

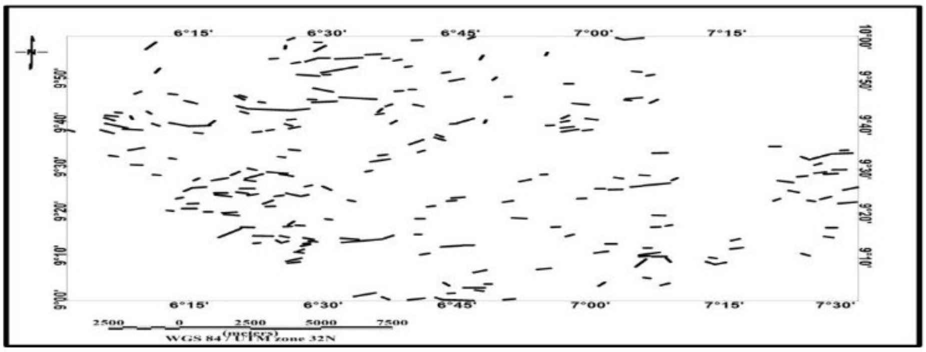

Figure 8: Vectorisation Lineament Map of the Study Area

Rosette Diagram

Analysis of the mapped lineaments (Figure 4.5) was used to determine the trend of the foremost faults, fractures and lithological contacts in the study area. The lineaments were plotted on rose diagram (Figure 4.5) in order to identify the most dominant structural trends that reflect the origin of the tectonic activities in the area. A general outlook on the plotted rose diagram (Figure 4.5) shows that the orientation of the most prominent lineaments trend in the East-West (E-W) direction, while minor ones trend towards the North-South (N-S) and Northeast-Southwest (NE-SW) directions. It is assumed that the lineaments trending towards the E-W direction are the oldest and deepest (that is the earliest structural orientations formed) while the lineaments trending towards the N-S and NE-SW directions are younger and the shallowest. In this regard, younger and the shallowest lineaments trending towards the N-S and NE-SW directions are the geologic structures perhaps harbouring vital deposits of minerals because they corroborate to the Foliation trends of the Schist Belt of Nigeria particularly within the study area.

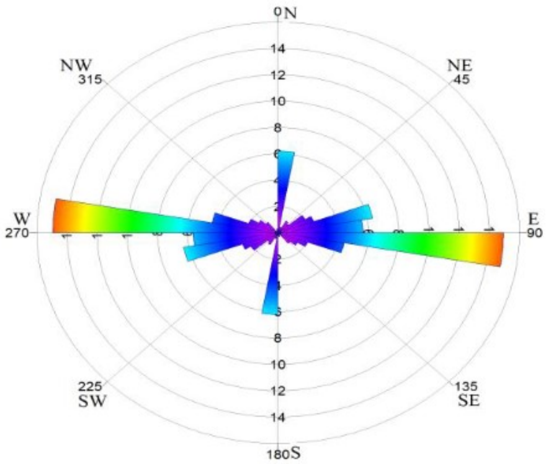

Figure 9: Rose Diagram showing the Trends of Lineaments in the Study Area

Source Parameter Imaging (SPI)

The Source Parameter Imaging (SPI) algorithm implanted in the Oasis Montaj software was applied to the TMI-RTE grid of the study area. SPI is used for calculating source depths to magnetic source. It is a tool based on the extension of the complex analytic signal to estimate magnetic depths. The derived map (Figure 9) highlights the spatial location of various magnetic sources at different depths. It also shows that the magnetic bodies in the area are generally shallow. The depths are characterized by high and low magnetic susceptibility. However, the anticipated depths characterized by pink/purple colour ranging from 1125.73 m to 12.39 m are the probable depth to magnetic lineaments perhaps hosting the deposits of vital minerals. In comparison with the AS Map (Figure 6) of the Study Area, the SPI map (Figure 9) shows a good similarity with the depth map derived using the AS filtering technique.

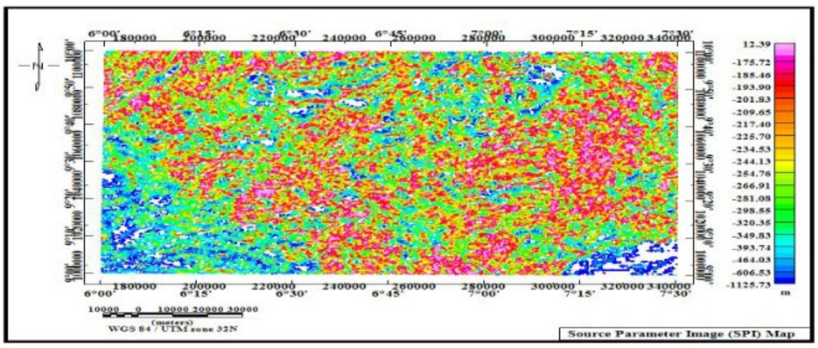

Figure 10: Source Parameter Image (SPI) Map of the study area. Colour Bar at the Right Side Signifies the Depths of the Lineaments Measured in Meters (m)

CONCLUSION

This research work considered the use aaeromagnetic data sets to delineate geological structures associated with mineralization zone via mapping of lineaments perhaps hosting vital mineral deposits. The aeromagnetic data used was in form of the six (6) TMI grids each designated as sheet 163 (Zungeru), 164 (Minna), 165 (Bishini), 184 (Bida), 185 (Paiko), and 186 (Abuja) covering the study area, thereafter grid knitted into a unified sheet that represents the TMI map of the study area using the Geosoft® Oasis Montaj™ version 8.4 software package. The new TMI map of the study area was subjected to different forms of filtering techniques so as to enhance the edges of magnetic anomalies assumed to be lineaments. The produced maps of each techniques used, agrees with each other by revealing the trends of the lineaments that could possibly host solid minerals. Source Parameter Imaging (SPI) also revealed the average depths of geological structures. Basic dykes and quartz veins are the surface manifestations of NE-SW trend in Basement complex. The revealed lineaments may be inferred to indicate a complex interplay of tectonic activities due to multiple deformational episodes in the area. This may be likely mineralisation zones.

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