Original Research Article

Analytic Signal Method (Hilbert Solution) For the Investigation of Iron-Ore Deposit Using Aeromagnetic Data of Akunnu-Akoko Area, Southwest, Nigeria

ABSTRACT

Aim: Investigation of iron ore deposit cannot be overlooked because of its economic importance and demand by steel industries. Hence, this paper aimed at providing clear information about the existence of iron ore deposit in Akuunu-Akoko area.
The Study Location: The Akunnu-Akoko area is located between latitude $7^{o}35^{1}$N and $7^{o}42^{1}$N and longitude $5^{o}55^{1}$E and $6^{o}00^{1}$E respectively. Aeromagnetic data sheet 245 was acquired from the Nigerian Geological Survey Agency (NGSA).
Methodology: The acquired data were processed and interpreted using an analytic signal method (Hilbert solution) in order to calculate susceptibilities of rocks in the area which further enhances the investigation of the speculated iron ore deposit in the study location.The minimum curvature method was applied to create an aeromagnetic image map, 3D image map, vector map and contour map for the area respectively.
Results: The magnetite type of iron ore was suspected in the area with a high susceptibility range 0.07 - 0.14. Maps obtained revealed magnetic high and low in the area. Magnetite gneiss, granite gneiss, periodolite, pure dolomite and iron ore mineralization were delineated which is in agreement with the geology of the area.
Conclusion: The study location is characterized by high and low magnetic values with preponderance of iron-ore within latitude $7^{o}42^{1}\ 00^{11}$ to $7^{o}\ 42^{1}\ 18^{11}$ and longitude $5^{o}\ 55^{1}$ to $5^{o}\ 57^{1}$ of the entire area.

Key words: Minimum-curvature, analytic, Akunnu, aeromagnetic, iron-ore, susceptibility

1.0 INTRODUCTION

Aeromagnetic maps represent magnetic-field variations caused by differences in the total magnetization of underlying sources. Total magnetization is the vector sum of induced and remanent components. The induced component of a rock is the product between the Earth's present-day magnetic field vector and the magnetic susceptibility. Magnetic susceptibility is a scalar measure of the quantity and type of magnetic minerals in the rock. The remanent component is based on the permanent alignment of magnetic domainswithin magnetic minerals and is measured using paleomagnetic methods [1].Magnetic susceptibility is basically the fundamental parameter of magnetic survey which is used for mineral and hydrocarbon exploration, as it reflects changes in the subsurface geologic structures and this property of rocks vary from place to place below the earth's surface. This variation in the magnetic susceptibility can cause small variations in the magnetic fields of rocks measured on the surface [2].Susceptibility mapping is an analytical process in which the observed magnetic field is directly inverted into a susceptibility contrast distribution. Calculation of the apparent susceptibility map assumes that the magnetic field has been corrected for the International Geomagnetic Reference (IGRF), that magnetization is by induction only and that all magnetic responses are caused by a collection of vertical square-ended prisms of infinite depth extent [3].

Since susceptibility is an analytic process, then analytic signal technique (Hilbert solution) can be used for mapping susceptibility of rocks beneath the earth surface in order to understand the source of magnetization in any study area of research interest to investigate metallic mineral deposit, like iron ore deposit which is the case in this study.

Analytic signal method was utilized in this study because it is the primary method for investigation of metallic mineral as the case in this research. It is fast, cover a large area within a short period of time, its ability to delineate the geological structure and basement relief. Magnetic surveying is ideal for both reconnaissance and focused surveys. It is expedient and cost effective, covers more ground in less time, and requires a minimum of field support. The choice of Akunnu Akoko area for this study is as a result of information available and understanding of geophysical setting of the area. This research aimed to investigate the metallic mineral deposits in Akunnu Akoko area of Ondo State, Nigeria in order to bridge the gap in the previous studies in the area.

1.1 DESCRIPTION AND GEOLOGY OF THE STUDY AREA

Akoko region of Ondo State is located at the fringe of southern rainforest and northern savanna grassland of Nigeria. Akoko takes a large percentage of local governments in Ondo State. Of the present 18 Local Government Areas (LGAs) in the State, four are from Akoko region and they include Akoko Northeast, Akoko Northwest, Akoko Southeast and Akoko Southwest [11]. The area falls on Precambrian basement complex of Nigeria. Akunnu Akoko is located at Akoko Northwest Local Government area of Ondo State, Southwestern Nigeria. It covers latitude $7^{0}36^{1}$N to $7^{0}42^{1}$Nand longitude$5^{o}55^{1}$E to $6^{0}00^{1}$E. It sheared boundary with Kabba, Kogi State. The rocks present in the area include migmatites, granite, charnockite, granite gneiss and felsic and mafic intrusives [10].

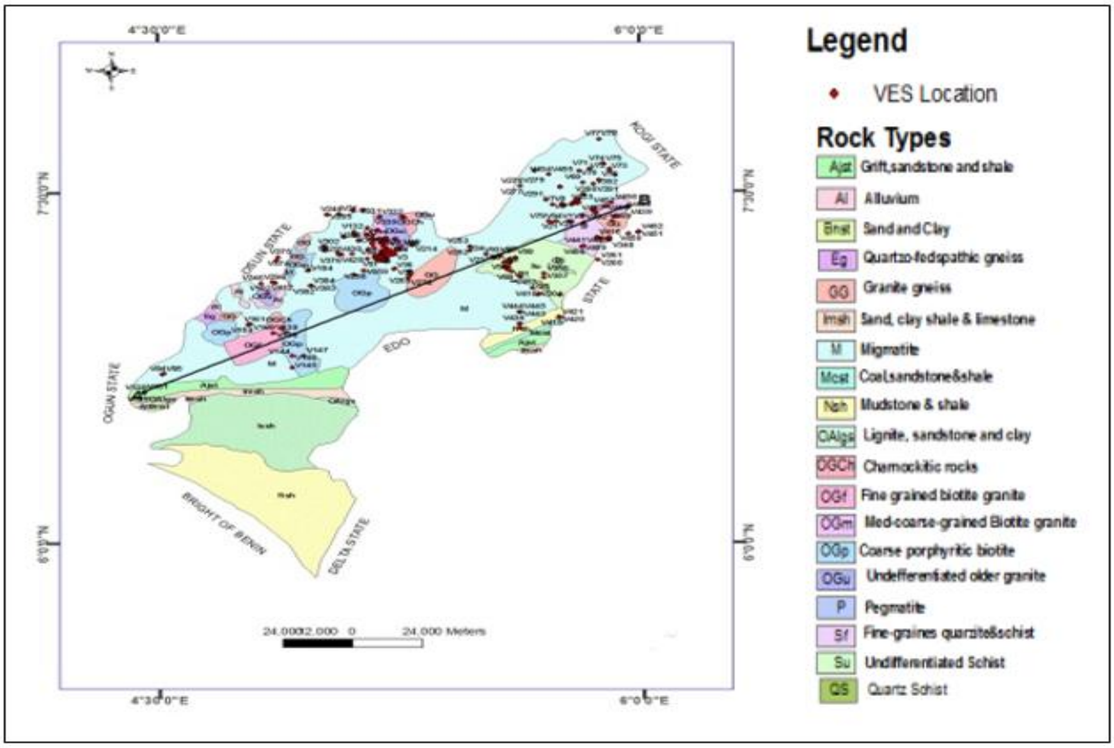

Figure 1: Geology of Ondo State (Adjusted after [16]).

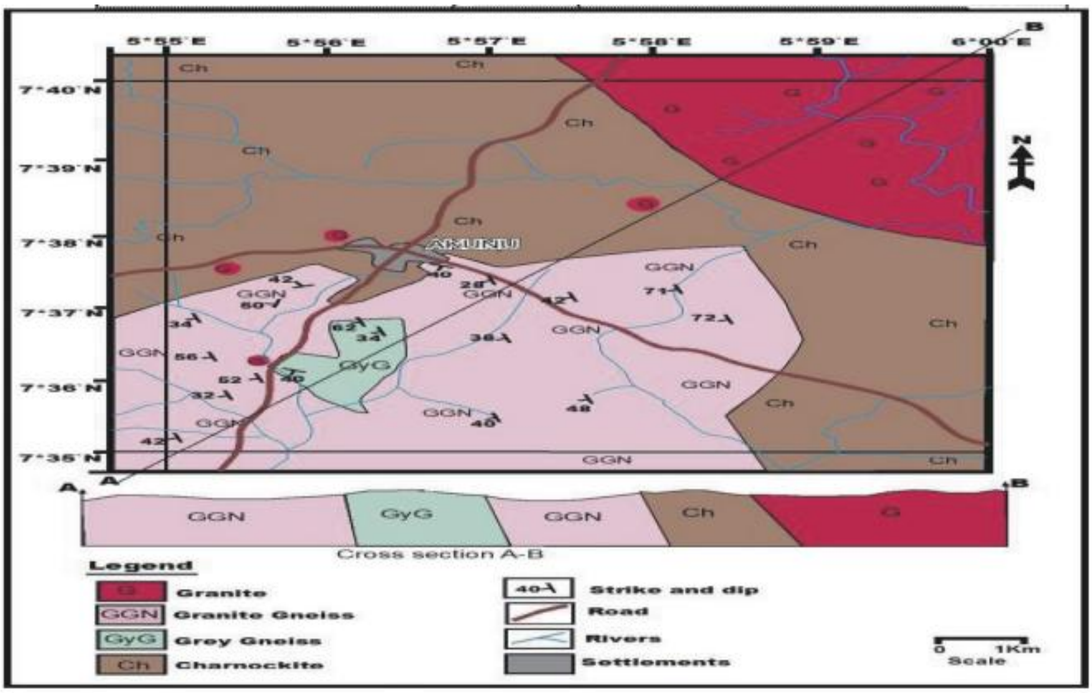

Figure 2: Geology of Akunnu Area [10].

2.0. MATERIALS AND METHODS

2.1 Data Acquisition

The data used for this research is the aeromagnetic data sheet 245 (Figure 3) acquired from Nigerian Geological Survey Agency (NGSA). The aeromagnetic survey was carried out between 2004 and 2007 by Fugro Airborne Survey Ltd for Nigerian Geological Survey Agency. The sheet 245 falls on phase 1 Block B of the survey which covered 235,000 line kilometres. The flight line spacing was 500 metres and the terrain clearance was 80 metres. The flight direction was oriented in NW – SE direction and the tie line spacing was 2 Km which was in NE – SW direction [12]. Scintrex CS3 Cesium Vapour magnetometer was used for data acquisition. Since this survey was carried out in air, the magnetometer was fixed in a stringer in the tail of the aircraft to reduce the effect of the external magnetic field from the aircraft. The aeromagnetic sheet 245 covered part of Ekiti State, Kogi State, and Ondo State.The data has been reduced to the pole during the pre-data processing by Fugro Airborne Survey Ltd.

2.2 Data Correction

Reduction to the pole (RTP) transformation usually involves an assumption that the total magnetizations of most rocks align parallel or anti-parallel to the Earth's main field [13]. RTP corrects the shift between the source and magnetic anomalies due to the non-vertically of both normal field and the magnetization [14].

Minimum Curvature (MC) surface is the smoothest possible surface that will fit the given data values. MC is based on inverse distance average of the actual data within a specified search radius [15], and was used for the gridding process using Surfer 10 software after the data has been pre-processed in Oasis montaj software. To get good result, 100% iteration and 99% pass tolerance was used for gridding process. The gridded data was digitized using the coordinate of Akunnu Akoko area. Digitization was necessary to get only data for Akunnu Akoko area. The output of the digitized data was an ASCII test-file containing x, y, and z i.e. longitude, latitude and total magnetic intensity (TMI) respectively. The total data points were 1,115 with TMI reduced to the pole ranged between -123.31 nT to 336.43 nT. Analytic signal (Hilbert solution) was used in calculating the susceptibilities which is very crucial in delineating rocks and mineral deposit in the area.Aeromagnetic image map, 3D image map, vector map, contour map and susceptibility map were created for Akunnu Akoko area.

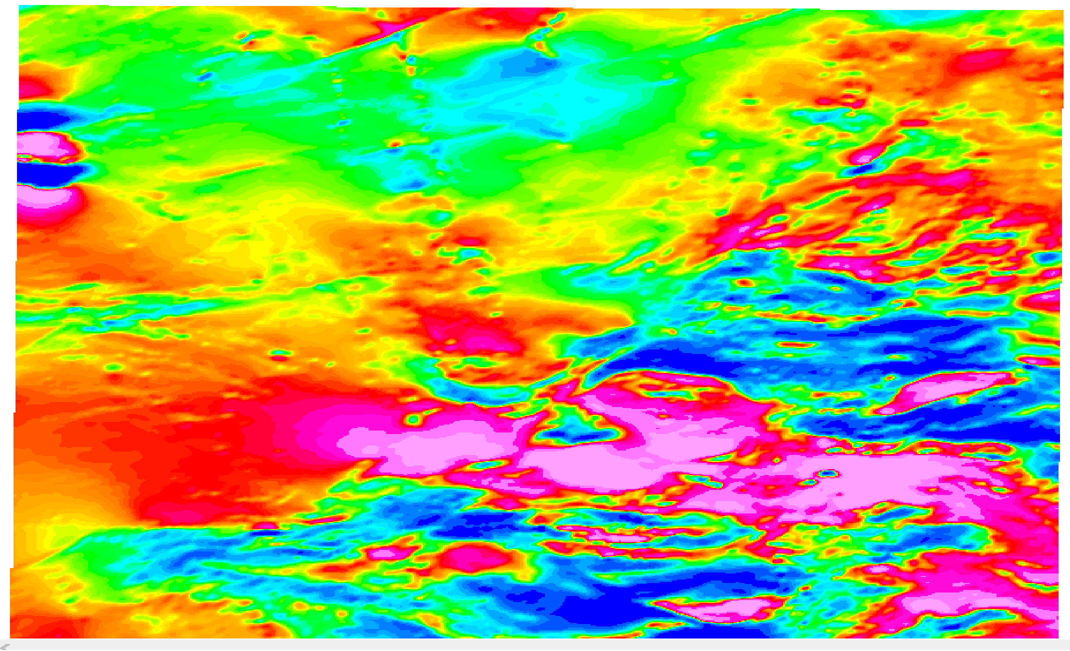

Figure 3: Sheet 245 Total Magnetic Intensity (TMI) grid

2.3 Theoretical Framework of Analytic Signal Method (Hilbert Solution)

The concept of the analytic signal for magnetic interpretation was introduced in 1972 by Nabighian. The analytic signal can be applied either in space or frequency domain, generating a maximum directly over discrete bodies as well as their edges. Its amplitude is independent of the magnetization direction. The analytic signal or total gradient is formed through the combination of the horizontal and vertical gradients of the magnetic anomaly [4, 5].The amplitude *A* of the analytic signal of the total magnetic field F is calculated from the three orthogonal derivatives of the field, being defined as the square root of the sum of squares of the data derivatives in the x, y and z directions of the magnetic field [6].

$$|A(x,y)| = [(\frac{\partial F}{\partial x})^2 + (\frac{\partial F}{\partial y})^2 + \left(\frac{\partial F}{\partial z}\right)]^{\frac{1}{2}} \quad (1)$$

$A(x, y)$is the amplitude of the analytic signal and F is the observed total magnetic field at (x, y). The horizontal and vertical derivatives are the real and imaginary parts of a complex analytic signal. Analytic signal can be used to generate Hilbert solutions which consist of x,y,z data, horizontal distance, Z-Both, Z-Dike, Z-Contacts, Geoid height, Dip, Susceptibility, horizontal gradient, Analytic Signal Magnitude, and Analytic Signal Horizontal Gradient. Susceptibility of rocks can be derived from equation 2.

$$\vec{B} = \mu_o(\vec{H} + \vec{M}) = (1 + k)\mu_o\vec{H} = \mu_r\mu_o\vec{H} = \mu\vec{H} \qquad 2$$

From equation 2, $\mu = (1 + k)\mu_o$, then

$$k = \frac{\mu}{\mu_o} - 1 \qquad 3$$

where $\vec{B}$ is the magnetic induction, $\vec{H}$ is the magnetic intensity, $\vec{M}$ is the magnetization of rocks, μ_o is the magnetic permeability of vacuum, μ_r is the relative magnetic permeability, $\mu$is the magnetic permeability and $k$is the susceptibility of rocks.

In a research [7] conducted to determine the area for detail investigation of mineral occurrences in Nigeria for national resource database, Ondo State was not listed for iron-ore deposits. In a study [8]to examine the environmental conditions of mineral processing sites in the Niger Delta area of Nigeria with reference to Ondo State, Akunnu Akoko area was listed as part of locations in Nigeria where iron ore can be found. A ground magnetic survey [9] was performed where iron ore deposit was suspected in the area but the area covered was 200 m by 200 m which is a small area to make a good conclusion about the iron ore deposit in the area. Geologic and ground magnetic survey method was used to reconstruct and appraise the iron ore deposit in Akunnu Akoko area [10]. Three different locations were covered in the area [10] which cannot be used to generalize Akunnu Akoko area because of limitations of ground magnetic survey. Among the limitations of ground magnetic survey are; settlement area cannot be covered, it is difficult to take measurement where there is large outcrop of rocks and busy area cannot be covered with ground magnetic survey. Aeromagnetic survey method is a better way of covering all area of interest without the above stated limitations. So far, little attempt has been made to delineate the subsurface structure of Akunnu Akoko area in large scale to investigate the iron ore deposit in the area.

3.0 RESULTS AND DISCUSSION

3.1 Minimum Curvature Filtered Data Map

The total magnetic map of AkunnuAkoko area (Figure 4) showed low, intermediate and high magnetic anomaly. The low magnetic anomaly labelled C has values ranged between -120nT to 40 nT. Any area of the map with blue and blue black colour represent low magnetic anomaly. That area of the map could be attributed to heamatite or magnetite that is deeply seated under sediment or low susceptibilities rocks near surface. Since aeromagnetic grid sheet 245 from which the digitization of AkunnuAkoko map was obtained has been reduced to the pole, it can be inferred that the causative bodies tend in North-West direction as shown by the anomalies. The intermediate anomalies represented with letter B was ranged between 40 nT to 140 nT with green colour being the dominant anomalies throughout the entire area of the map. The high anomalies with values ranged between 160 nT to 336.43nT represented with letter A and red colour. The area with concentrated high magnetic intensities was found to be between latitude $7^{o}42^{1}$ to 7^{o} 42^{1} 18^{11} and longitude 5^{o} 55^{1} to 5^{o} 57^{1}. This area is interpreted as the suspected area with concentrated iron ore mineral deposit in the Akunnu Akoko area.

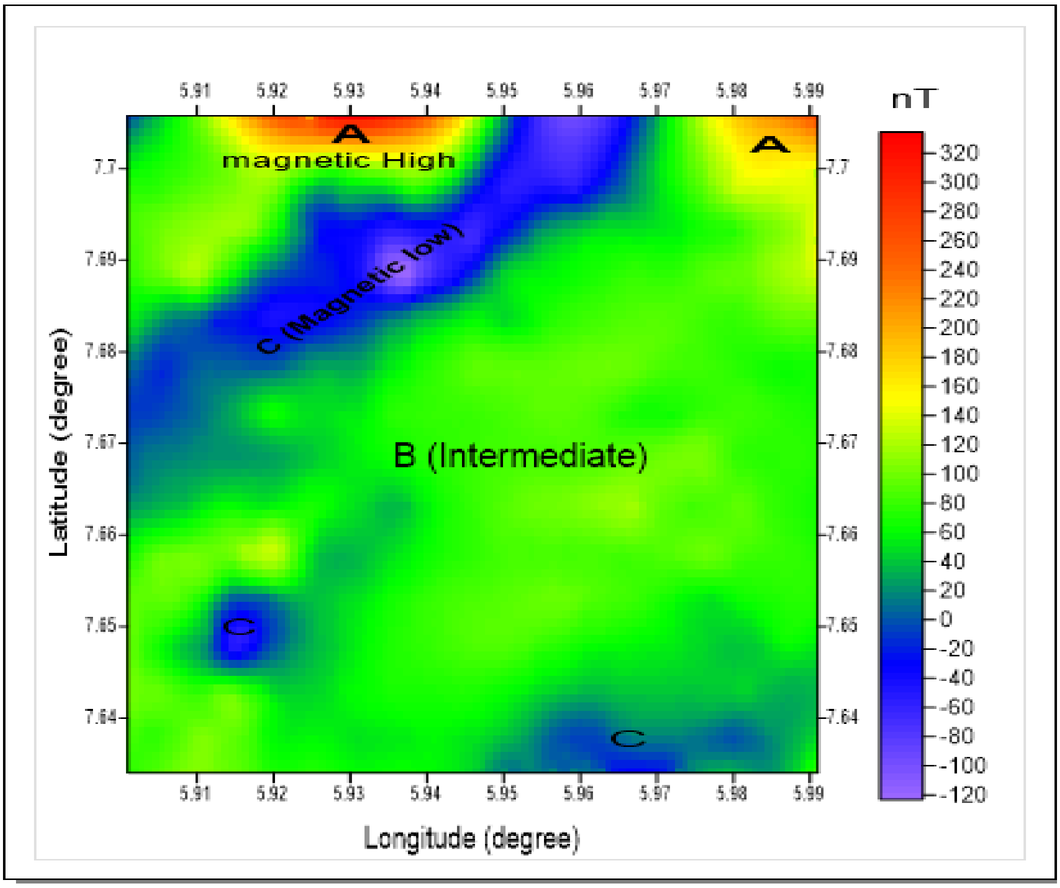

Figure 4: Aeromagnetic image map of digitized Akunnu Akoko data using minimum curvature

3.2 Contour Map at interval of 20 nT

The contour map of AkunnuAkoko area is presented in Figure 5. The north - west area of the map has the lowest value of -40 nT indicate region with very low magnetic susceptibilities compared to other area of the map. This is in agreement with result presented in Figure 5. The centre of the map and toward south east of the map has low contour and the little contour is widely spaced which represent shallow gradient. The area has 60 nT as the contour value which is the region with intermediate intensity. The north centre part of the map has 60 nTas the contour value and contour lines are closed together which represent area with higher magnetic susceptibilities.

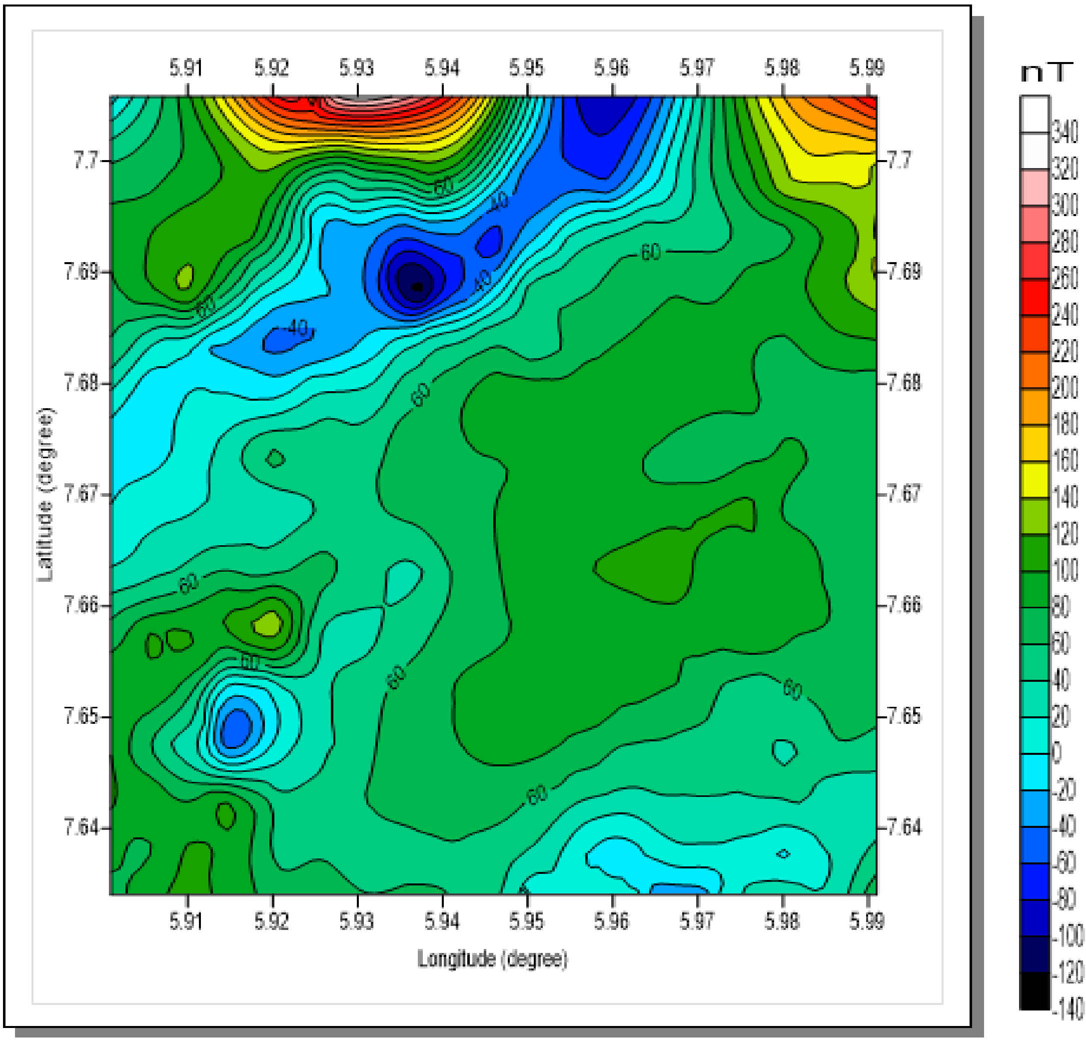

Figure 5: Contour map of Akunnu Akoko area with contour interval 20 nT.

3.3 The Map of the Magnetic Orientation and Total Field

Figure 6 gives nearly parallel dipoles pointing downward in most cases at the southern portion of the map and upward in some area in the north eastern area of the map which was interpreted as ferromagnetic material. At the centre north of the map, there is disorder in the direction of the dipole which indicate different magnetic materials of different susceptibilities and other properties. Disorderliness in dipole direction is also observed between latitude 7^{o} 37^{1} 36^{11} to 7^{o} 39^{1} 36^{11} and longitude 5^{o} 55^{1} to 5^{o} 56^{1}. Figure 7 clearly shows how total magnetic field in the area is distributed and how near or deep the causative body is to the earth surface. Locations marked X are deeply seated compared to other area of the map

3.4 The Susceptibility Map

The values of susceptibilities of rocks in AkunnuAkoko area varies between -0.11 to 0.14. The values of susceptibilities was grouped into four. The first group ranged between -0.11 – 0.00 and this values was interpreted to be pure dolomite which is a sedimentary rock and usually have negative susceptibilities. Blue colour dominates the area with negative susceptibilities as presented in Figure 8. The second group rangedbetween 0.01 – 0.03 which was attributed to magnetite gneiss. Gneiss is a metamorphic rock which can be a host for magnetite but in most cases host hematite. Both magnetite and hematite usually have iron ore mineral associated with them in various concentration. The third group ranges between 0.03 – 0.06 which was associated with granite gneiss. The last group ranges between 0.07 – 0.14 was interpreted to be periodolite and magnetite rich iron ore deposit.

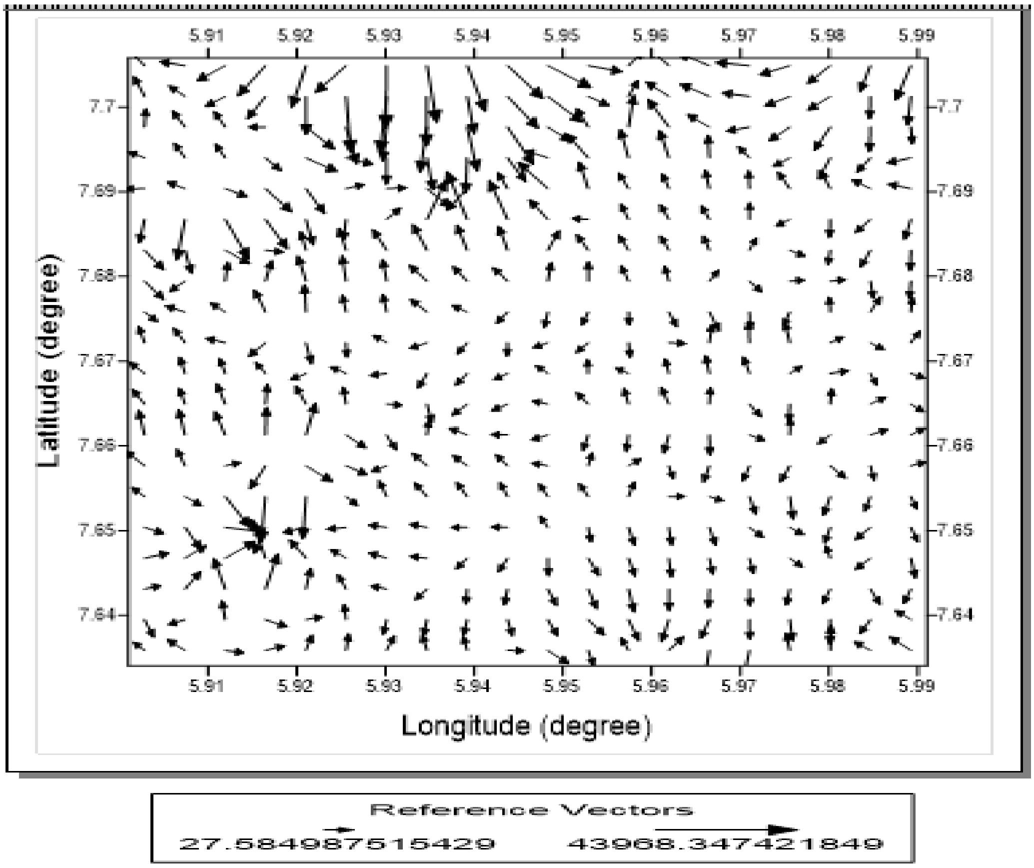

Figure 6: Vector map of AkunnuAkoko area.

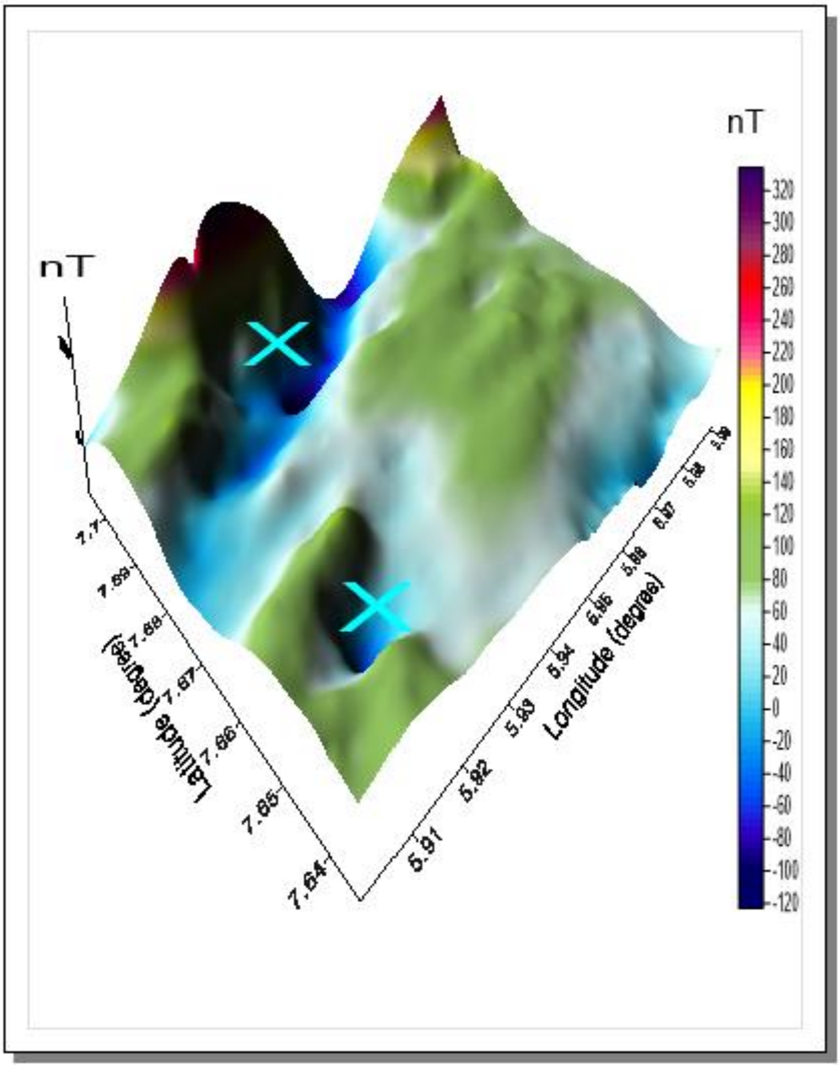

Figure 7: 3D image map of AkunnuAkoko area.

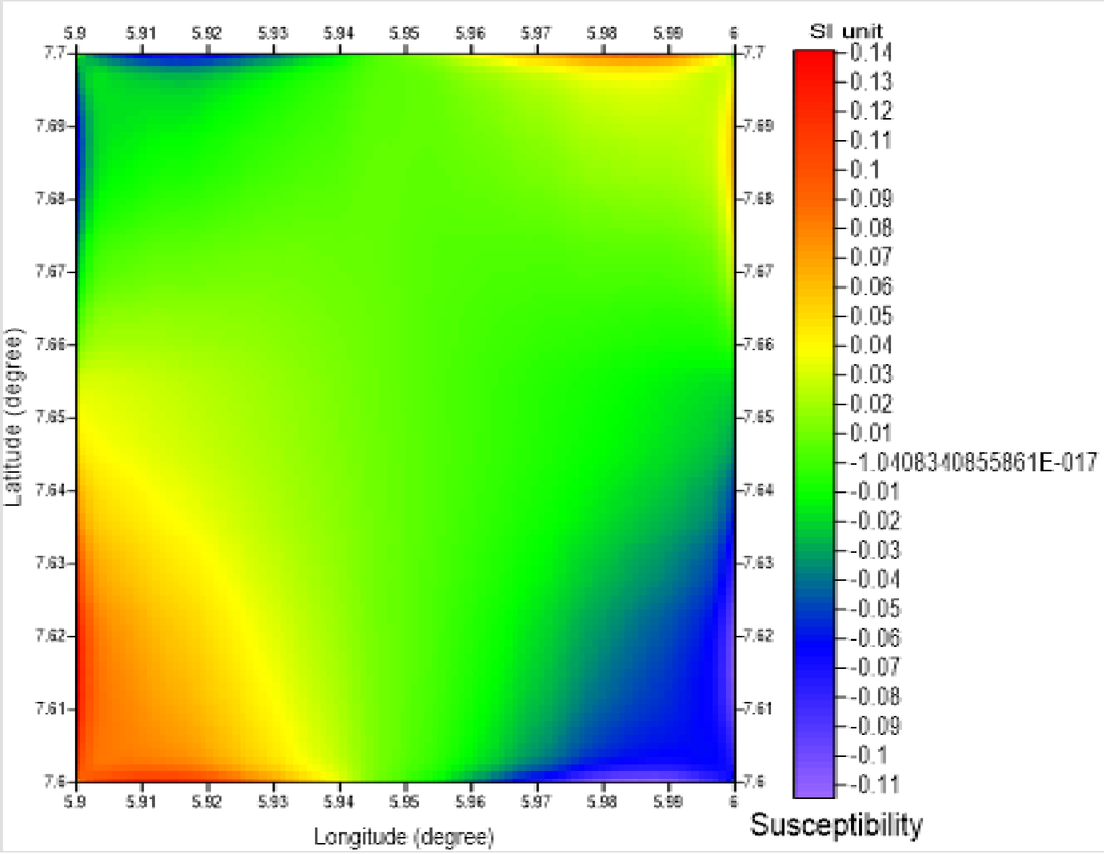

Figure 8: Susceptibility map of Akunnu Akoko area.

4.0 CONCLUSION

Aeromagnetic data sheet 245 has been processed to create aeromagnetic maps for Akunnu Akoko area of Ondo State, Nigeria which has helped for the investigation of iron ore deposit in the area. The maps presented in this research revealed that the area is characterized with magnetic high and magnetic low.The results of this work suggested that iron ore deposit could be targeted between latitude 7^o42^1 00^{11} to 7^o 42^1 18^{11} and longitude 5^o 55^1 to 5^o 57^1. The values of susceptibilities of rocks in Akunnu Akoko area was found to range between -0.11 to 0.14. Magnetite gneiss, granite gneiss, periodolite, pure dolomite and iron ore mineralization were delineated in Akunnu Akoko area which is in agreement with the geology of the area.

COMPETING INTERESTS

Authors have declared that there is no competing interest exists.

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