Physical Science International Journal

17(2): 1-9, 2018; Article no.PSIJ.39004
ISSN: 2348-0130

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

E. O. Joshua[1], G. O. Layade[2*] and S. O. Adewuyi[3]

[1]*Department of Physics, University of Ibadan, Ibadan, Nigeria.*
[2]*Department of Physics, Federal University of Agriculture, Abeokuta, Nigeria.*
[3]*Department of Mining Engineering, King Abdulaziz University, Jeddah, KSA, Saudi Arabia.*

Authors' contributions

This work was carried out in collaboration among all authors. The author EOJ conceptualized the research idea, Author GOL defined the methodology and made available the technical know-how of the procedures akin to the implementation of the methodology. Finally, author SOA analyses the data and compiled the results together while author GOL prepared the document for publication. All the authors approved the final document.

Article Information

DOI: 10.9734/PSIJ/2018/39004
Editor(s):
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(2) Christian Brosseau, Distinguished Professor, Department of Physics, Université de Bretagne Occidentale, France.
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(3) Kadiri Umar Afegbua, Nigeria.
Complete Peer review History: http://www.sciencedomain.org/review-history/23188

Original Research Article

Received 26th November 2017
Accepted 1st February 2018
Published 14th February 2018

ABSTRACT

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 Akunnu-Akoko area. The Akunnu-Akoko area is located between latitude 7.5833ºN and 7.7000ºN and longitude 5.9167ºE and 6.0000ºE respectively. Aeromagnetic data sheet 245 was acquired from the Nigerian Geological Survey Agency (NGSA). 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

**Corresponding author: E-mail: layadeoluyinka018@gmail.com;*

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. 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 was delineated which is in agreement with the geology of the area. The study location is characterized by high and low magnetic values with preponderance of iron-ore within latitude 7.7000º to 7.7050º and longitude 5º 55^1 to 5º 57^1 of the entire area.

Keywords: Minimum-curvature; analytic; akunnu; aeromagnetic; iron-ore; susceptibility.

1. 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 of 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 domains within 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.

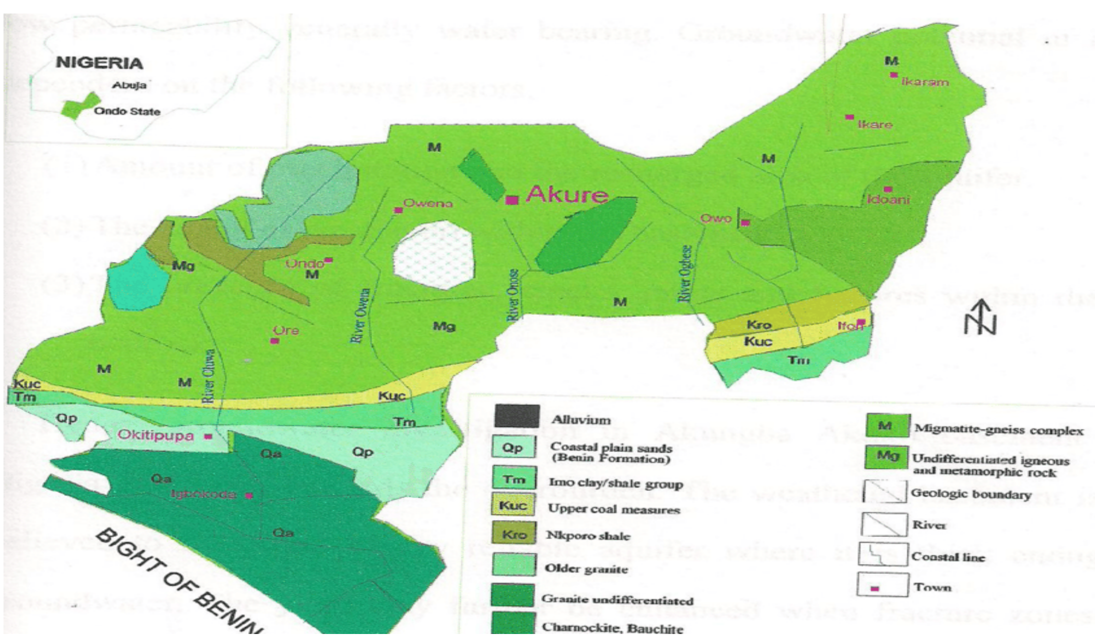

Fig. 1. Geology of Ondo State (Adjusted after [4])

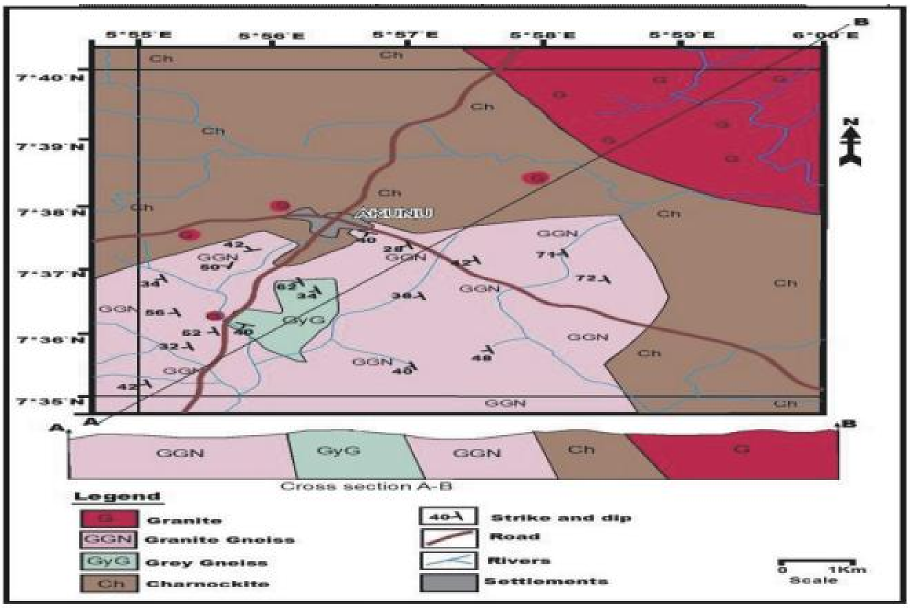

Fig. 2. Geology of Akunnu Area [5]

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 as shown in Fig. 1. 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 [6]. 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 7.5833ºN and 7.7000ºN and longitude 5.9167ºE and 6.0000ºE. It sheared boundary with Kabba, Kogi State. In Fig. 2, the rocks present in the area include migmatites, granite, charnockite, granite gneiss and felsic and mafic intrusives [5].

2. MATERIALS AND METHODS

2.1 Data Acquisition

The data used for this research is the aeromagnetic data sheet 245 (Fig. 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 [7]. 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.

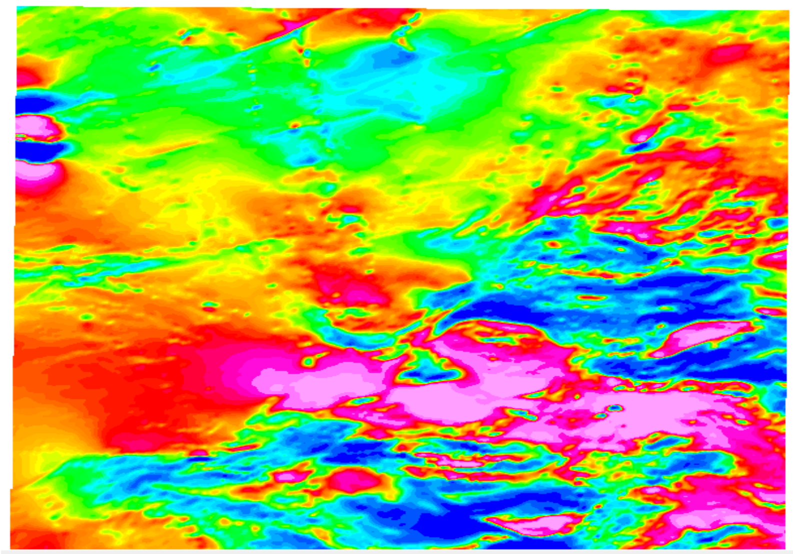

Fig. 3. Sheet 245 Total Magnetic Intensity (TMI) grid

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 [8]. RTP corrects the shift between the source and magnetic anomalies due to the non-vertically of both normal field and the magnetization [9].

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 [10], 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.

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 [11,12].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 [13].

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

$A(x,y)$ 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.

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

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

$$k = \frac{\mu}{\mu_o} - 1 \quad (3)$$

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 [14] 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 [15] 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 [16] 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 [5]. Three different locations were covered in the area [5] which cannot be used to generalize Akunnu Akoko area because of limitations of the ground magnetic survey. Among the limitations of the ground magnetic survey are; settlement area cannot be covered, it is difficult to take measurement where there is a large outcrop of rocks and the busy area cannot be covered with the 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 so as to investigate the iron ore deposit in the area.

3. RESULTS AND DISCUSSION

3.1 Minimum Curvature Filtered Data Map

The total magnetic map of AkunnuAkoko area (Fig. 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 a low magnetic anomaly. That area of the map could be attributed to haematite or magnetite that is deeply seated under sediment or low susceptibilities rocks near the surface. Since aeromagnetic grid sheet 245 from which the digitization of Akunnu Akoko 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 the 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 7.7000º to 7.7050º N and longitude 5.9167º to 5.9500º E. This area is interpreted as the suspected area with concentrated iron ore mineral deposit in the Akunnu Akoko area.

3.2 Contour Map at Interval of 20 nT

The contour map of AkunnuAkoko area is presented in Fig. 5. The northwest 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 Fig. 5. The centre of the map and toward the 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.

3.3 The Map of the Magnetic Orientation and Total Field

Fig. 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 indicates different magnetic materials of different susceptibilities and other properties. Disorderliness in dipole direction is also observed between latitude 7.6267º to 7.6600º N and longitude 5.9167º to 5.9333º E. Fig. 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.

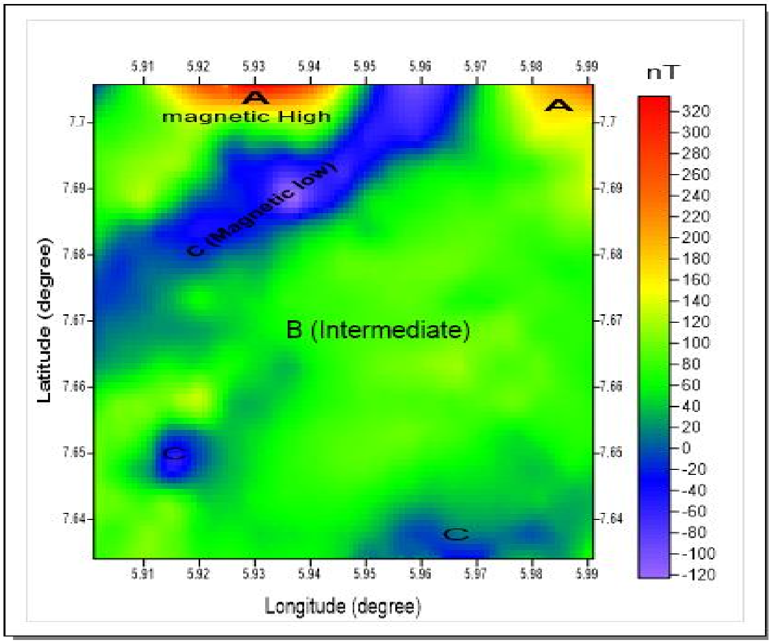

Fig. 4. Aeromagnetic image map of digitized Akunnu Akoko data using minimum curvature

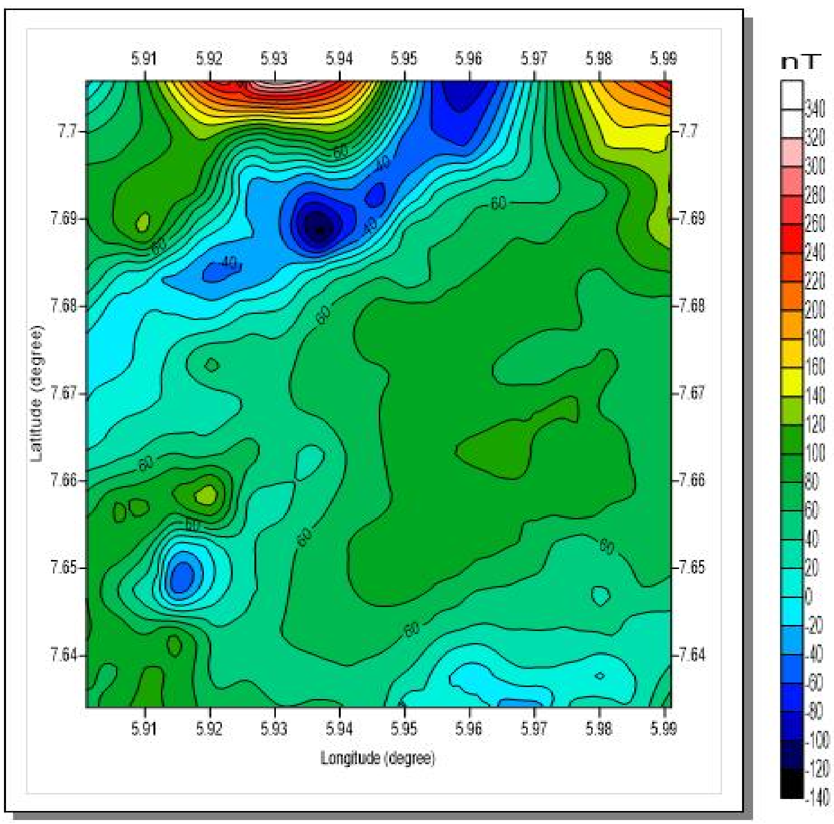

Fig. 5. Contour map of Akunnu Akoko area with contour interval 20 nT.

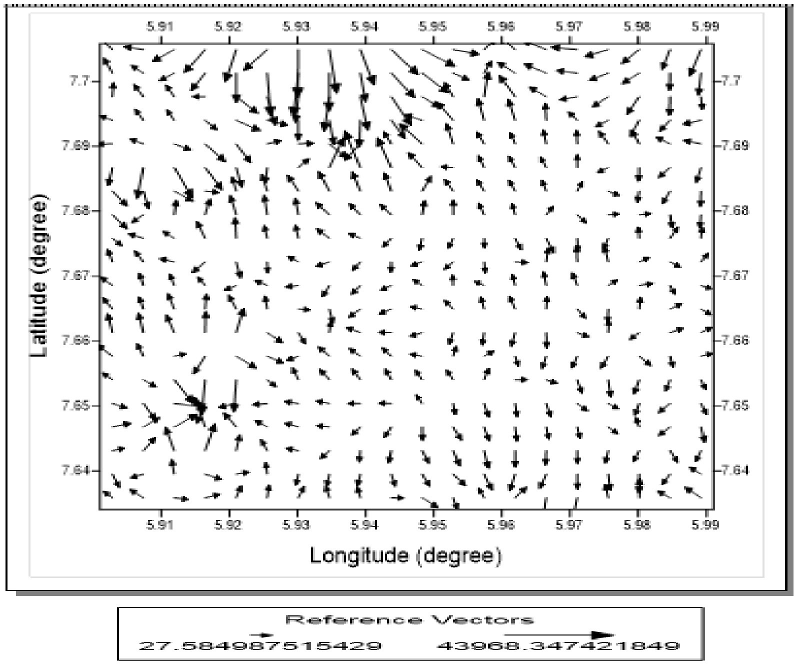

Fig. 6. Vector map of AkunnuAkoko area.

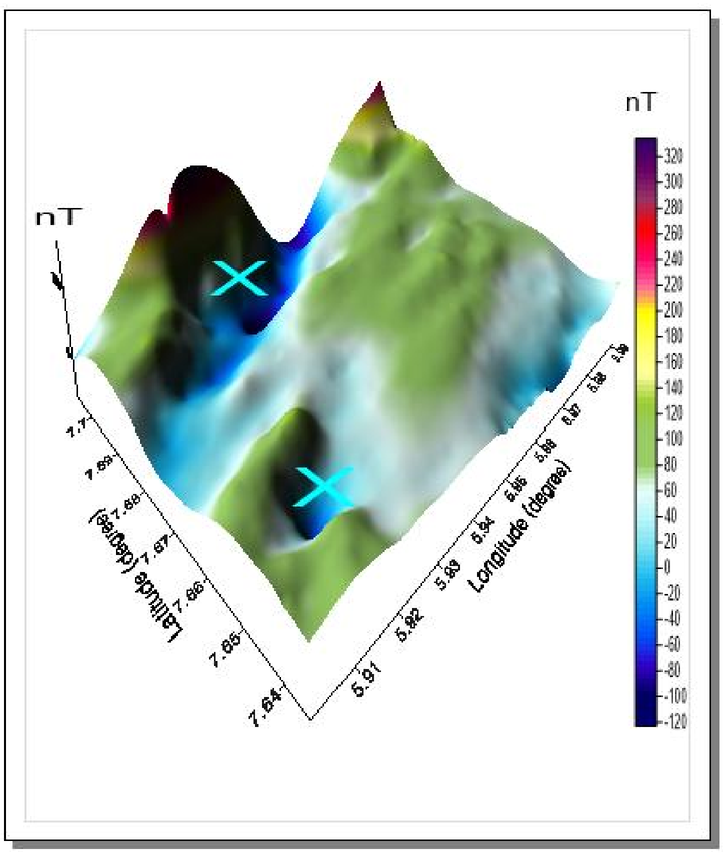

Fig. 7. 3D image map of AkunnuAkoko area.

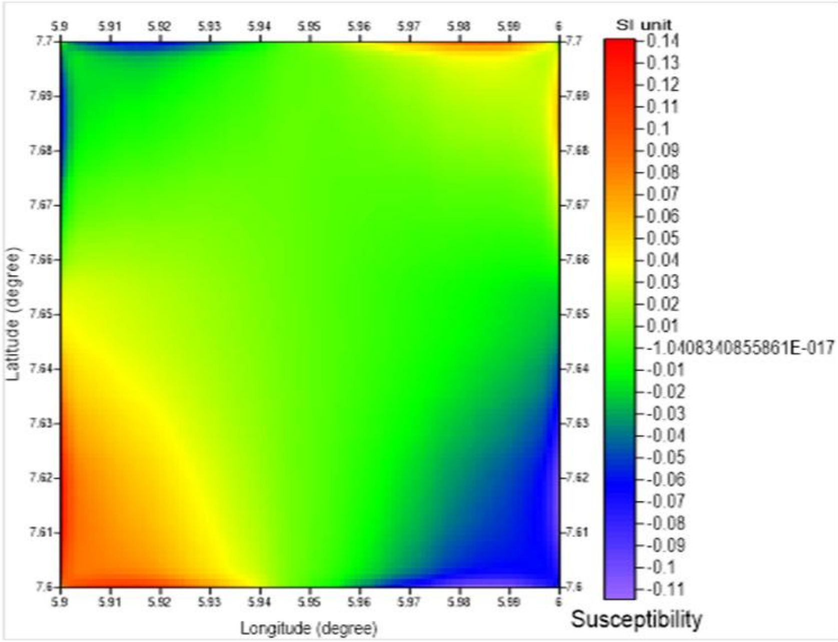

Fig. 8. Susceptibility map of Akunnu Akoko area.

3.4 The Susceptibility Map

The values of susceptibilities of rocks in Akunnu Akoko 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 above Fig. 8. The second group ranged between 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.

4. 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 7.7000^o to 7.7050^o N and longitude 5.9167^o to 5.9500^o E. 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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Peer-review history:
The peer review history for this paper can be accessed here:
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