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*RESEARCH ARTICLE*

# DELINEATION OF MINERAL COMPOSITION AND DEPTH OF BURIAL OF MAGNETIC ANOMALY IN ISIUZO L. G. A. EASTERN NIGERIA

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**ABSTRACT**

The aeromagnetic survey of Isi-Uzo was conducted by Nigeria Geological Survey Agency. 305,669 numeric data points make up the entire amount of Isi-Uzo data points. These data points were digitally captured (X, Y, Z text file) following the removal of the geomagnetic slope from the initial data set using the International Geomagnetic Reference Field (IGRF). Through the use of source parameter imaging, that was examined using Oasis montaj software, the depths of the magnetic source body were determined. The research area's magnetic intensity varies between -74.72 to 147.24 nT, at its lowest and maximum levels, respectively. There could be a dip or plunge, change in lithology, change in depth, variation in magnetic susceptibility, or angle of strike causing this fluctuation in magnetic strength. The SPI depth value varies with a minimum of 151.6 m for shallow depth magnetic bodies to a maximum of 3082.7 m for deep lying magnetic things. Thick sedimentation for hydrocarbon formation and mineral deposit is seen at depths ranging from 1200 m to 3082.7 m whereas shallow depths of 35 m to 150 m which are evident of excellent prospective sources of water. This work gives information that will be very important in mineral exploration and management for economic growth in the area.

**KEYWORDS**

Magnetic Anomaly; Isiuzo; Oasis Montaj, Magnetic Susceptibility; Forward and Inverse Modeling method.

## 1. INTRODUCTION

The call for economy diversification over the past fifty years have increased the need and demand to explore areas with reasonable accumulation of oil, gas and minerals/metals of all kind. Due to this search, Astronomers found an asteroid that contain mainly mineral and metal (iron and nickel) which is proposed to worth more ten thousand quadrillion USD apparently far much more that the world's annual budget. This increase in demand has necessitated the creation of several sensitive geophysical instruments for the identification, analysis and mapping of hidden minerals and formations. The detection of these minerals and metals beneath the earth surface is determined by those behaviors that makes them different from their surrounding media. Such characteristics include; the change in electrical conductivity and natural current in the Earth, local variations in gravity, magnetism and radioactivity.

Measuring at or close to the surface of the Earth which are impacted by its inner composition of physical attributes is known as geophysical exploration of the planet's interior. The physical characteristics of the earth's core can be analyzed to see how they differ transversely and longitudinally. Geophysical investigations are used to determine the fundamental parameter of the subsurface using seismic, electrical, magnetic and electromagnetic fields obtained at the surface of the earth or inside boreholes. Ground-based studies usually yield data regarding the subsurface laterally and to a certain depth, whereas the majority of borehole investigations with a few exceptions only yield comprehensive data about subsurface materials in the immediate vicinity of the borehole or along its interstitial boundaries.

Geophysical observations of the earth can also be obtained in specific situations from aircraft or above water (Keary et al., 2002). Generation of geological map is frequently facilitated by employing the latitude and longitude from aeromagnetic surveys which are widely employed during the quest for mineral exploration. Numerous deposited minerals are linked to magnetically rich minerals, and in most cases the most desired ores of iron deposits is typically a magnet. Most times, explaining the upper crust's surface structure is an extremely significant and helpful finding from the interpretation of aeromagnetic data (Burger et al., 2006). The key objective of the aeromagnetic investigation is to find rocks minerals which possess peculiar magnetization characteristics that identify them by creating abnormalities in the earth's magnetic field strength (USGS, 1997).

The aeromagnetic survey is applied in mapping these anomalies in the earth's magnetic field and this is correlated with the underground geological structure (Keary et al., 2002). Cracks are characterized by sudden shift or narrow separation in the alignment in their outlines as indicated by their magnetic anomalous bodies. Residual map of magnetic anomaly is helpful for detecting mineralogy and intrusive because they show where magma circulates, volcanic rock connects, and intrusive are present. Ground magnetic surveys are always recommended because they give true information which aid in validating that the subsurface

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conditions that are detected using geophysical techniques are as precise as they can be.

However, aeromagnetic data interpretation within the Lower Benue Trough have been extensively carried out successfully, many researchers carried out this analysis mainly within Abakaliki, Nsukka and environ using different methods like Euler deconvolution, spectral analysis approach, Source Parameter Imaging (SPI) and Forward and Inverse modeling approaches to ascertain the depth and thickness of the sedimentary basin, the type of mineral that is most common in the region as well as the magnetic susceptibilities (Ugbor and Okeke, 2010; Ezema et al., 2014; Obiora et al., 2015; Obiora et al., 2016a; Obiora et al., 2016b; Edeh et al., 2017; Obiora et al., 2018). Results from SPI estimated depth revealed depth for outcropping and magnetic substances that have shallow depth and those that are deeply bedded arguing that the mineral deposits at the observed depths are thick enough to support the buildup of hydrocarbons. Their results within Abakaliki revealed five intrusive bodies composed of basalt, pyrite, and granulites.

The intrusive are found between 2.4 and 6.32 kilometers below the surface. The majority of dolerite intrusive was discovered at depths of 2.7, and 3.6 km at Idemba-Iza and Abba Omega respectively. In their work, they showed that Nsukka comprises of substantial thick layered strata of shale, clay, ironstone and sandstone, iron-rich minerals such as limonite, hematite, pyrrhotite, and pyrite, which mostly form lateritic caps on sandstones, which when combined are appropriate for the manufacturing of ceramics and have thick strata sufficient enough to allow the storage of hydrocarbons confirming the earlier speculations that some parts in the area contains reasonable amount of hydrocarbon.

A group researcher studied the search for coal deposits in the northeastern portion of the Sokoto basin, Nigeria using aeromagnetic data and traces of coal mineral in the Dukanmaje Formation of the Gada Local Government Area of Sokoto State (Narimi et al., 2019). The Nigerian Geological Survey Agency (NGSA) provided the aeromagnetic data, which they processed, analyzed and interpreted using geophysical based software such as Surfer and Oasis Montaj. The study's findings point to several possible locations for in-depth geophysical coal exploration: Gada, Dukanmaje, Kwakwazo, Kaddi and KyadawaHolai. These locations have extremely low magnetic susceptibility values (highly negative) and long-wavelength magnetic anomalies that are uniform over longitudes along with evidence of coal in the nearby surface areas.

A studied on aeromagnetic anomalous analysis of the Mount Nemrut Stratovolcano (Bitlis, Eastern Turkey) employing potential field data analysis methods to investigate the geological processes that created the magnetized traces (Ekinci et al., 2020). The near-surface morphology in the research region and the aeromagnetic aberrations were generally compatible, according to the image maps that were produced after a few linear modifications and a derivative-based method. A few strong magnetic anomalies that have been detected to the northern part of the Nemrut caldera rim are linked to the most recent bimodal volcanic activity that has been characterized by comenditic-basaltic outflows and fountains of lava across the fracture zone.

In order to identify high resolution aeromagnetic and Shuttle Radar Topography, looked at aeromagnetic and satellite-based data regarding the structure in the middle of the Niger and Sokoto basins, Nigeria (Naheem et al., 2020). Survey data obtained from the Middle Niger and Sokoto Basins, which are located along the N-S axis of western Nigeria, present an integrated image of the terrain. It also delineates the limits of the sedimentary basins down to 950 meters below the surface, defining the two basins' governing structural setting. Magnetic structures were revealed by the three-dimensional analytic signal applied to the aeromagnetic data, and the source parameter imaging technique was used to determine the depths of the magnetic bedrock.

The results revealed a number of structural characteristics that trend E-W, NW-SE, NNE-SSW, and ENE-WSW. Of these, two are associated with the NNE-SSW trending Anka–Yauri–Iseyin and Kalangai–Zungeru–Ifewara zones of shear that were generated within the Pan-African orogeny. They located a region directly west of the Anka-Yauri-Iseyin stress region, which connects the Sokoto and Middle Niger Basins near the Libata-Auna area. Geophysical study of the fault zone of aeromagnetic data across the Ageva region of Okene-Kogi State, Nigeria was interpreted for the aim of estimating sedimentary a thickness in the studied area (Ahmed et al., 2021). The outcomes were more reliable due to the regional residual adjustment as well as the reduction of data to noise ratio through upward continuation to a height of 250 m. The study area's anomalies trend in the E-W, NE-SW, NW-SE, and N-S directions. Qualitative interpretation techniques like the slant derivative, analytic signal, and second vertical derivative were used to identify these tendencies. The findings indicate that the fault zones in Ageva and Owo might be mineralized, and that the faults in Ageva and Ibilo are only 25% of their total revealed length. Deduced fractures inside Owo and Ibilo might have minimal susceptibilities when related to other research areas, according to Werner's solutions, and the total depth of the linear characteristics ranges from 401.5 m to 982.5 m. (Yakubu et al., 2020; Eke and Nelson, 2021; Lawal et al., 2021; Mohamed and Gonclaves, 2021; Naheem et al., 2021; Okpoli and Akinbulejo, 2021; Omokparilo and Anakwuba, 2021; Ullah et al., 2021; Mulualem et al., 2022; Rabo et al., 2022; Widyawati et al., 2022).

## 2. Geology, Latitude and Longitude

Isi-Uzo has the following geological formation; carbonaceous shale, siltstone, clay, fine-medium grained sandstones, and bands or seams of impure coal. Degraded remains from this formation are called outliers, and many springs emerge from its borders. These springs are primarily connection springs that emerges at the boundaries of the Isi-Uzo formation's sandy units. Between latitudes $6^{o}2^{1}$ to $6^{o}59^{1}$ N and longitudes $7^{o}2^{1}$ to $7^{o}31^{1}$ E, the study area spans approximately 877 square kilometers and consists of multiple water wells drilled by the federal government and the state water board under the previous National Borehole Program. Its thickness varies between more than 120 m around Eha-Amufu and a mean of about 70 m.

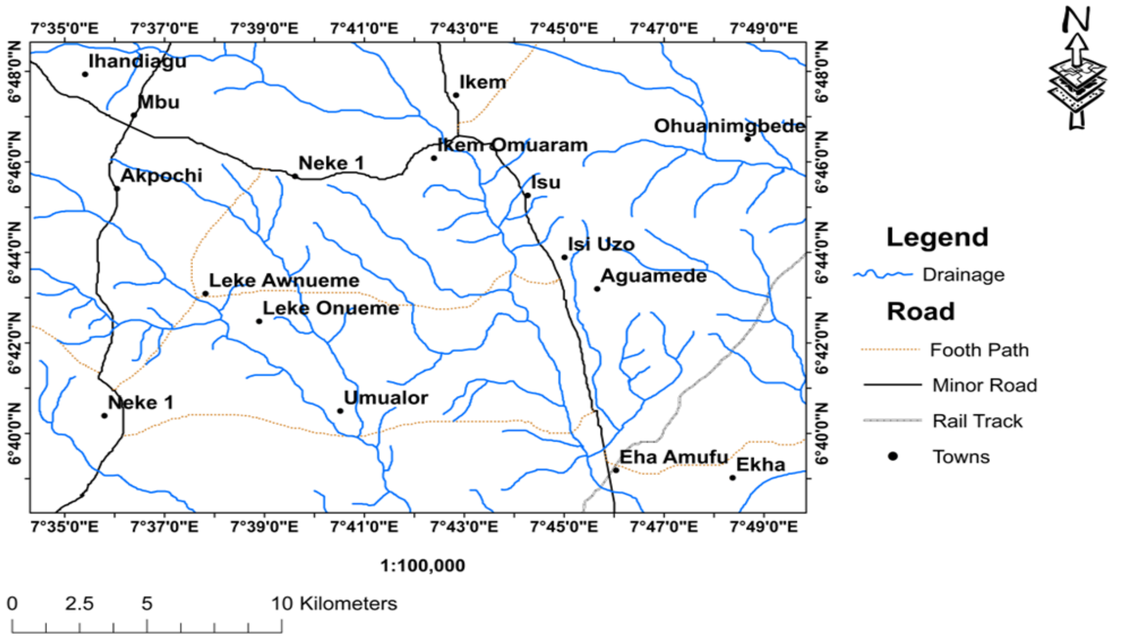


**Figure 1:** Map showing towns and villages in the study area.

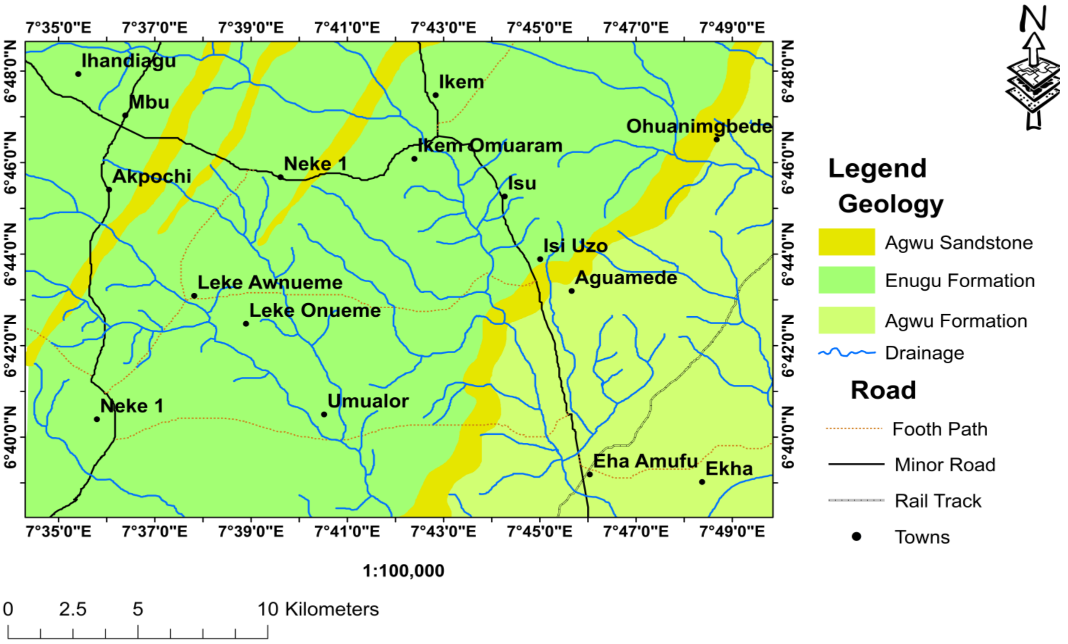


**Figure 2:** Map showing the geologic features of the study area.

## 3. Source of Data, Theoretical Background and Methodology

The results of magnetic surveys are shown as a collection of lines or as a magnetic contour map; while there could be some similarities between gravity and magnetic maps in sedimentary areas, magnetic anomalies are typically many, less regular, and greater in size than gravity anomalies. Information from an aeromagnetic survey is usually too enormous for manual processing and analysis; hence a distinct method is used for processing them than for marine and aerial data. This results in the analysis of the acquired data using contemporary computer. Aeromagnetic data consist of three data types: ground station data, position resolution (usually in a format containing station identification codes converted to collections of aerial images or topographical mapping), and the magnetic field data (primary data).

The Nigeria Geological Survey Agency District, Gariki Abuja carried out the aeromagnetic study of the research region (Isi-Uzo sheet) in three stages from from 2005 to 2010. The World Bank and the Nigerian Federal Government partially funded the study, as a component for a larger project called Sustainable Management for Mineral Resources by FURGO Airborne surveys. The measurement features a 500-meter tie-line separation, a 100-meter-spacing aircraft path in an East-West direction, an 80-meter height, with a 100-meter topographic elevation. 305,669 data make up the entire amount of Isi-Uzo sheet data points. These data points were digitally captured (X, Y, Z text file) following the removal of geomagnetic variation from the raw data employing the International Geomagnetic Reference Field (IGRF). The magnetic field intensity, expressed in nanoTeslas, is represented by the Z, while Nsukka's longitude and latitude, expressed in meters, are represented by the X and Y.

### 3.1 Basic concepts of magnetic prospecting

The Earth's magnetic field is determined since geologic features, such as fractures and mineral deposits, frequently create a secondary magnetic field that modifies the planet's primary magnetic field. Assessing the magnetic field close to the ground's surface will reveal such magnetic variations. According to Coulombs (1736–1806), the force between two charged points is comparable to the magnetic force (F). Coulombs demonstrated that an inverse square law, similar to the one Newton derived for gravity, similarly governs the force of attraction or repulsion between two electrically charged things and between two magnetic poles. This prompted Coulomb to develop the torque equilibrium. As a result, the real force acting between two magnetic poles is known as magnetic force.

$$F = \frac{m_1 m_2}{\mu r^2} \quad (1)$$

where μ is the magnetic permeability, a dimensionless constant the magnetic material's capacity to encourage the creation of a magnetic field inside of itself and it also describes the magnetic property in which poles are situated. $m_1$and $m_2$are the pole strength separated by a distance. The torque that a unit magnetic pole would encounter at a location in a magnetic field produced by a pole intensity m, where r is the measuring point's distance from m, is known as the magnetic field strength ($H$).

$$H = \frac{F}{m'} = \frac{m}{r^2} \quad (2)$$

$\underline{H}$ is a vector quantity whose direction is defined by presuming the unit's pole is positive and whose magnitude is specified by Equation 2. The Oersted is the cgs unit of magnetic field strength, while the nanotesla, or nT, is the SI unit. One Oersted is equivalent to gammas and is defined as one dyne per unit pole strength (Burger 1992).

The force that a magnet will encounter in an external magnetic field is determined by its magnetic moment, a vector quantity. The magnitude of the couple is expressed in Eqn. 3.

$$c = 2(ml)\underline{H}\sin\theta \quad (3)$$

where $\theta$ It describes the magnet's initial position within the field. The quantity$(ml)$ is termed the magnetic moment, M, so that$M = (ml)$. It is measured in Newton-meters per Tesla. (Burger 1992)

**Intensity of Magnetization** is the fundamental property a magnetic material must possess per unit volume known. The magnetic moment M per unit volume determines the magnitude $I$ $I = \frac{M}{volume}$ (4)

therefore, $I = \frac{M}{volume} = \frac{m}{area}$ (5)

**Total magnetic field induction (*H*)** is experienced when the electric current in the liquid outer core of Earth, which is made up of extremely conducting molten iron, is primarily responsible for the planet's magnetic field's response. When iron is exposed to a magnetic field, H, the magnetic material undergoes induced magnetization, which is the creation of magnetization on its own. A dimensionless ratio variable called magnetic susceptibility (k) describes how magnetized a material becomes in response to any induced magnetic field. Magnetization corresponds with the magnetizing field at weak field strength which is expressed in Eqn. 6.

$$I = k\,\underline{H} \quad (6)$$

Thus, as a key rock parameter of magnetic prospecting, k is the constant of proportionality often known as magnetic susceptibility. $\underline{I}$ is induced magnetization per unit volume and $\underline{H}$is the magnetic field intensity.

### 3.2 Data Analysis

We used forward and inverse modeling in our data analysis. These techniques or procedures comprise the following: (i) utilizing Oasis montaj software to create a total magnetic intensity (TMI) grid for the study region (ii) choosing profiles and creating subsets using the potent built in the Oasis montaj software (iii) modeling the profile subsets to determine the depth of burial of anomalous bodies, magnetic anomalies

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are caused by the body's form, dip, strike, and susceptibilities to different types of rock in the vicinity using forward and inverse modeling.

## 4. Results and Discussion

Interpretation usually has qualitative and quantitative approach.

### 4.1 Total Magnetic Intensity

The types of potential structures and geological formations that could have produced the obvious magnetic anomalies which were revealed by the airborne magnetic survey describes and explains major features using the qualitative interpretation of the generated maps. The information about the geological features was extracted qualitatively by merely inspecting the total magnetic intensity map. The research's total magnetic intensity (TMI) map, which shows various color aggregates, is shown in Figure 3. The research area's magnetic intensity values spans from -80.00 to 160.00 nT. Both the low (gray color) and high (bright blue color) magnetic signatures identify the area. This change in magnetic strength may be caused by lithological differences, dips, plunges, variations in depth, variations in magnetic susceptibility, and degrees of strike, among other factors.

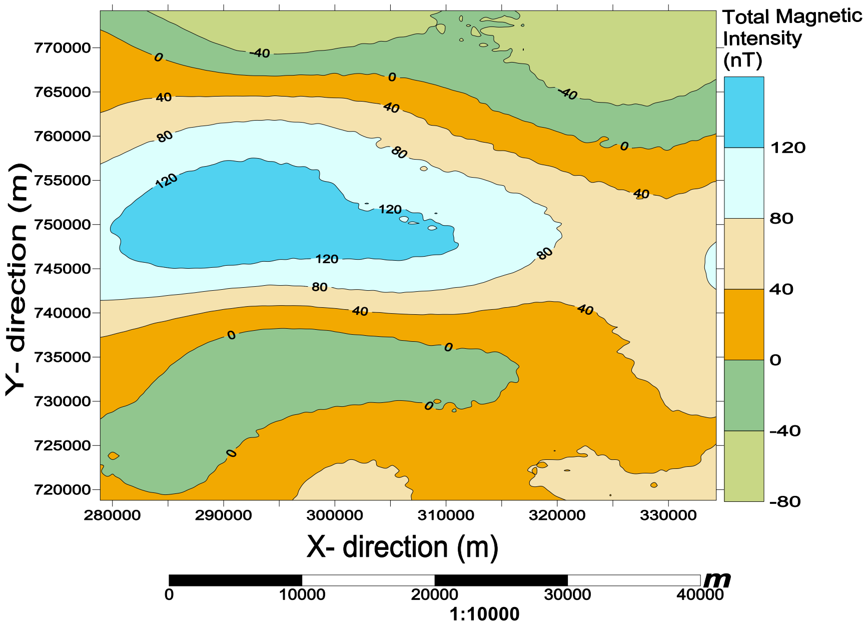


**Figure 3:** Total intensity magnetic susceptibility grid of the study area.

Interpretation of aeromagnetic data quantitatively entails estimating the depth and size of the anomalies numerically. This can be done by using a variety of methods, such as spectral analytical, analytical signal, Euler 3D, forward and inverse modeling, graphical interpretation, and source parameter imaging (SPI). Forward and inverse modeling technique was applied in this study. The purpose of magnetic data filtering is to highlight anomalies and obtain fundamental knowledge about the area's magnetization. Mathematical procedures like convolution and correction can be utilized for filtering, residualizing, continuation, etc. In the science of magnetic, Fourier transforms are very helpful for resolving certain anomalies by downward or upward continuation, modifying the inclination of the effective field (reduction to pole), computing derivatives, and other methods (Bhattacharyya and Navolio, 1976).

One technique used in this research to filter the noise produced by the rapid Fourier transform is upward continuation filtering. It is possible to estimate a potential field using the assumption that it were measured on a different plane by measuring it at a constant height on a certain observation plane. By projecting the surface above the original datum, this process smoothes the abnormalities found on the earth's surface. The entire magnetic intensity data was projected 500 meters above the initial datum plane. Figure 4 displays the total magnetic field intensity (TMI) map's upward continuation. The region's magnetic intensity varies from a minimum of -65.82 nT to a maximum of 137 nT, as indicated by the upward continuation map.

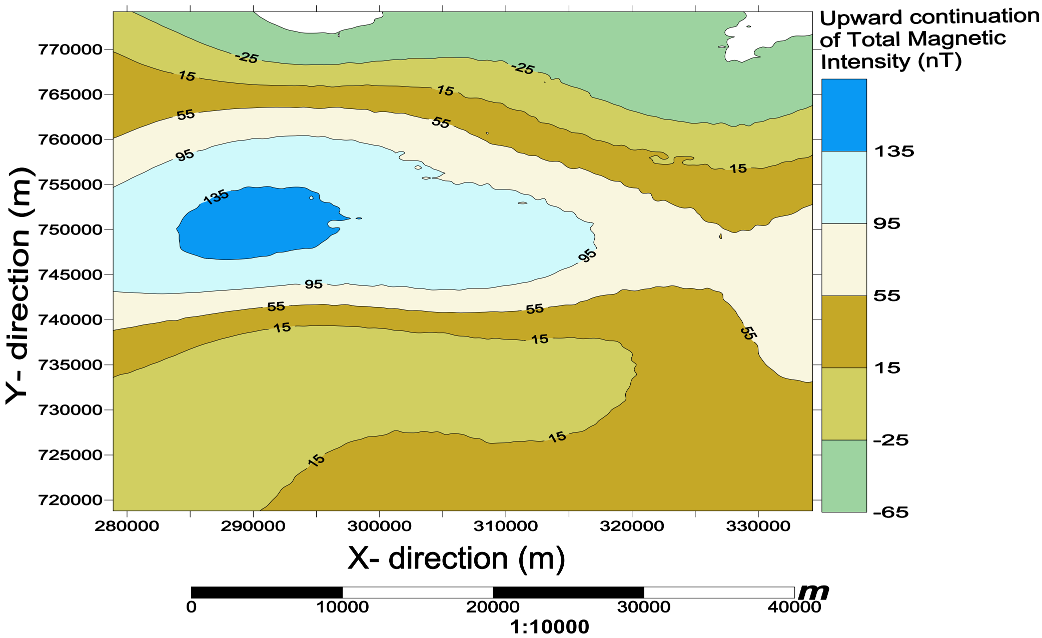


**Figure 4:** Upward continuation of TMI of the study area

## 4.2 Estimation of Depth and Possible Deposited Mineral Using Forward And Inverse Modeling Method

Potent software contained in the Oasis montaj was used for this process. Experimental testing is the method used in forward modeling to compare calculated field and observed field while inverse modeling is the opposite. Inverse modeling gives direct information of the main cause the anomaly from the measured data. The eight profiles from the contoured upward continuation TMI grid are displayed in Figure 5. Figure 6 (a, b, c, d, e, f, g, h) is the subsets showing the observed, calculated and residual field of the eight profiles that we used for modeling.

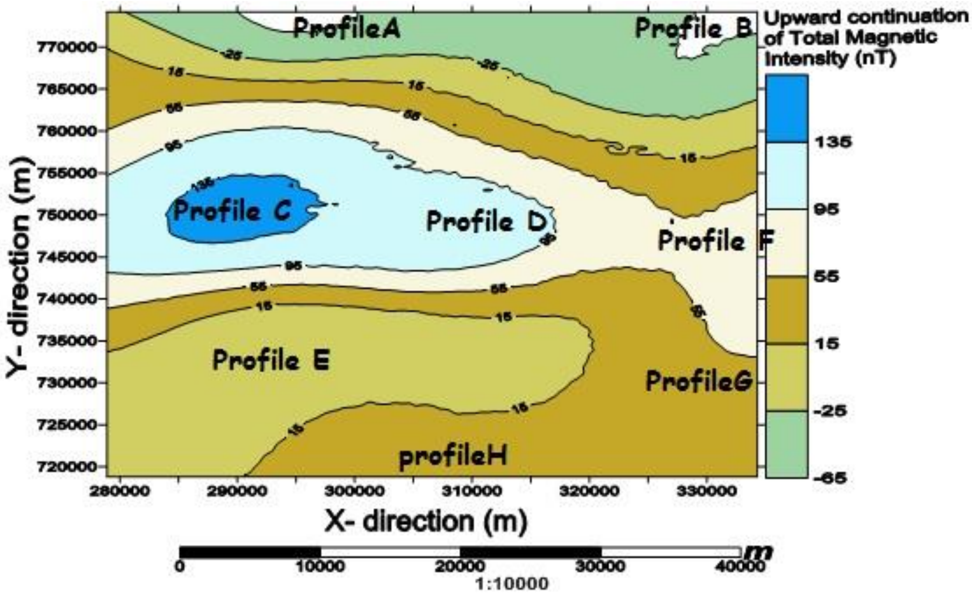


**Figure 5:** map showing total magnetic intensity variation with eight modeled profile locations.

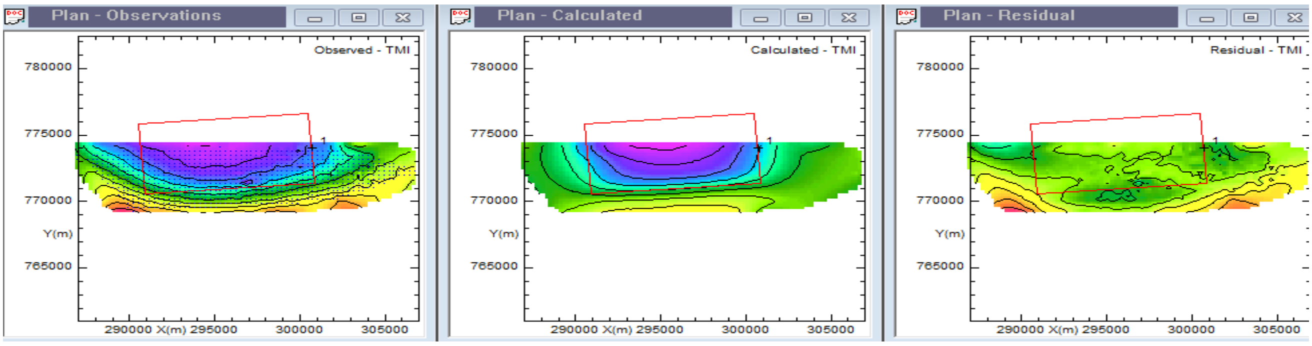


**Figure 6a:** Profile A subset

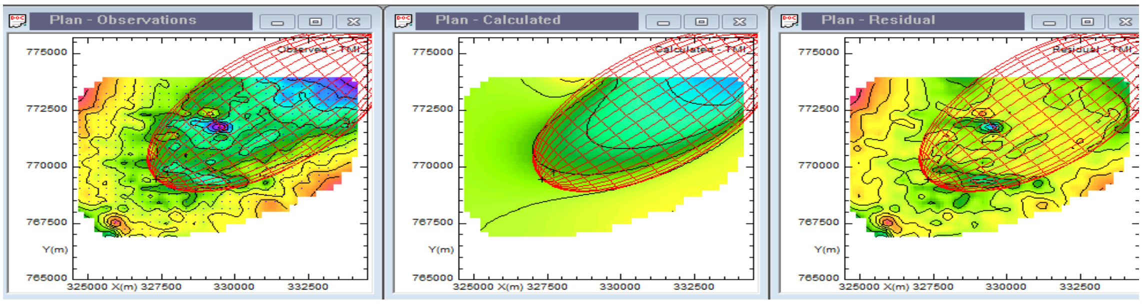


**Figure 6b:** Profile B subset

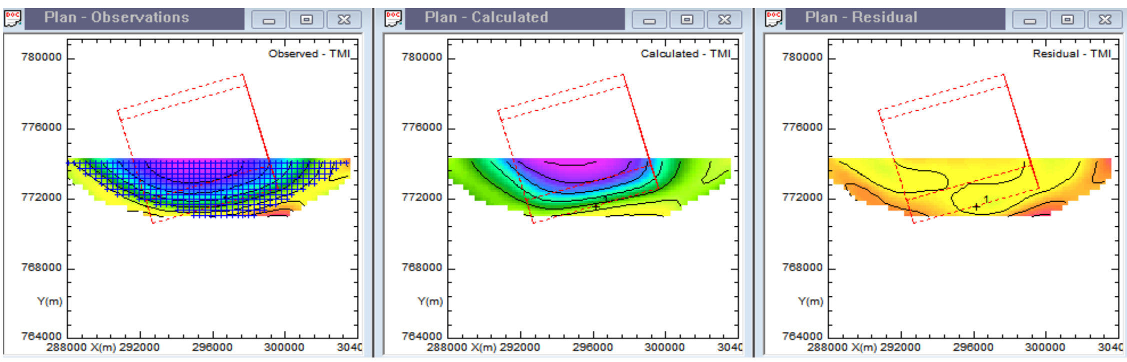


**Figure 6c:** Profile C subset

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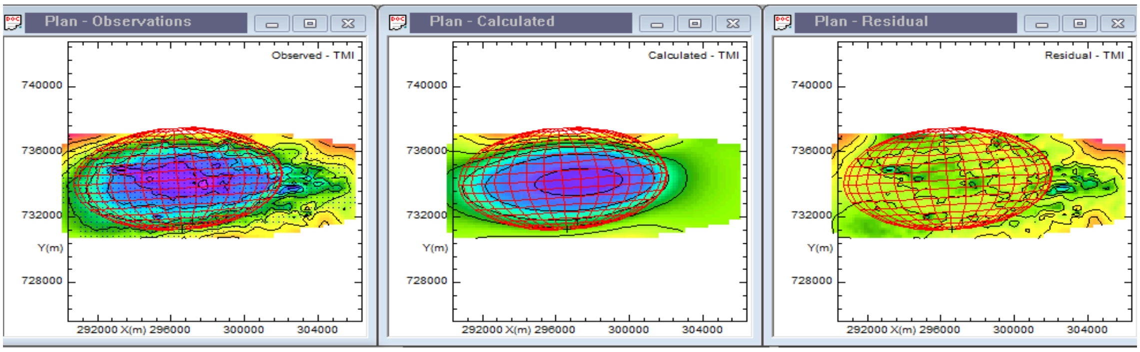


**Figure 6d:** Profile D subset

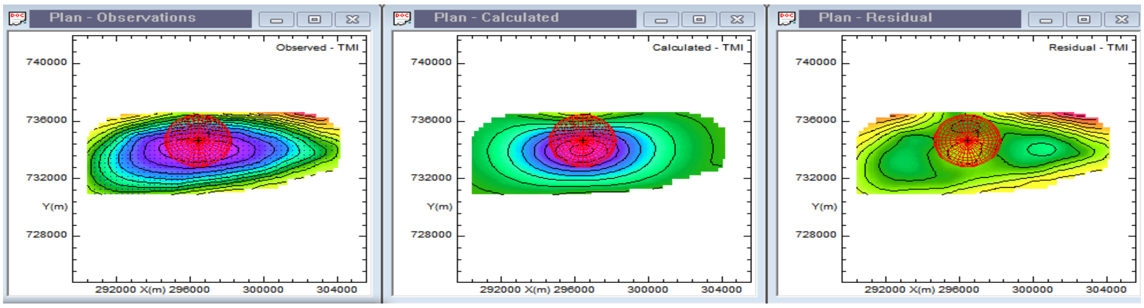


**Figure 6e:** Profile E subset

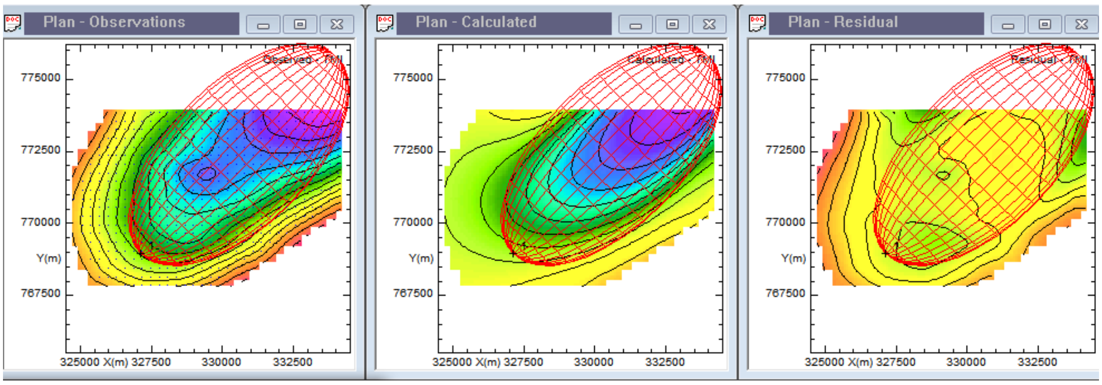


**Figure 6F:** Profile F subset

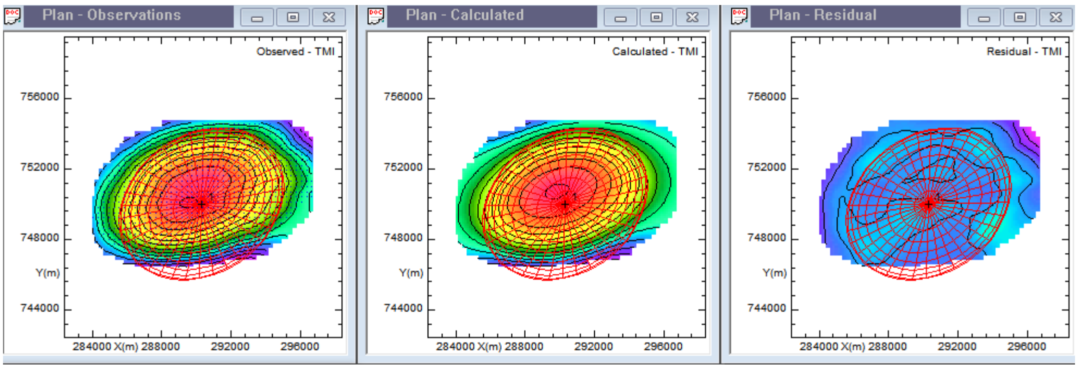


**Figure 6g:** Profile G subset

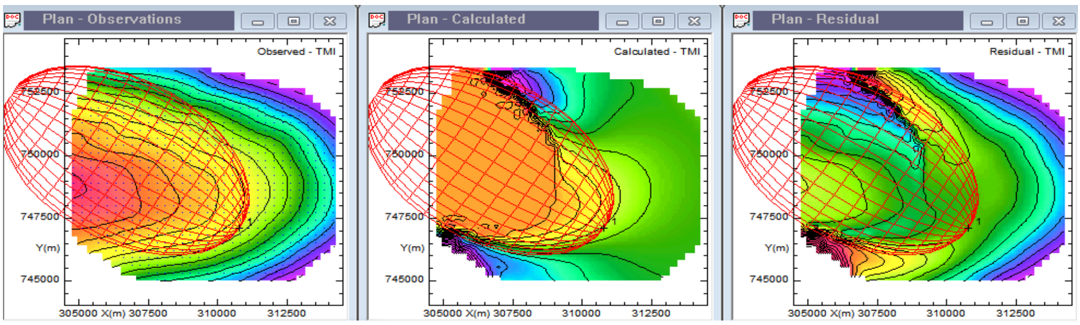


**Figure 6h:** Profile H subset

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Eight (8) profiles were acquired for this modeling, and it is anticipated that each profile will have a degree of strike, dip, and plunge where the predicted values and observed values agree well. The red curves in Figures 7 (a, b, c, d, e, f, g, and h) represent the estimated field values, whereas the blue curves represent the observed field values. We changed the physical attribute (sucs), form, and orientation since forward modeling is an iterative procedure that requires fine tuning in order to suit the computed and observed fields accurately, then the inbuilt potent package in Oasis montaj software computes the model's field.

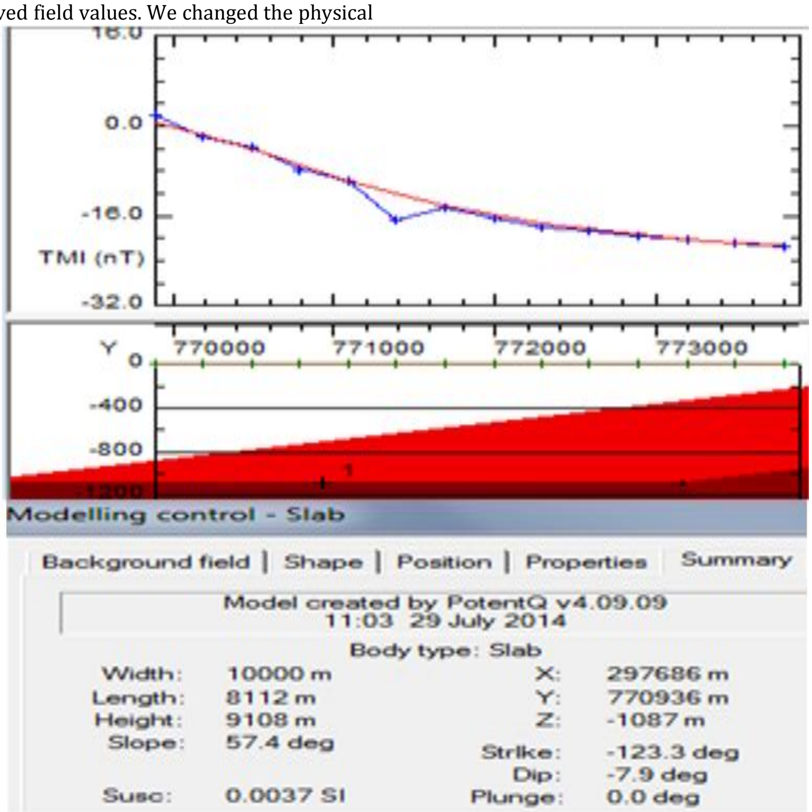


**Figure 7a:** Profile model for A

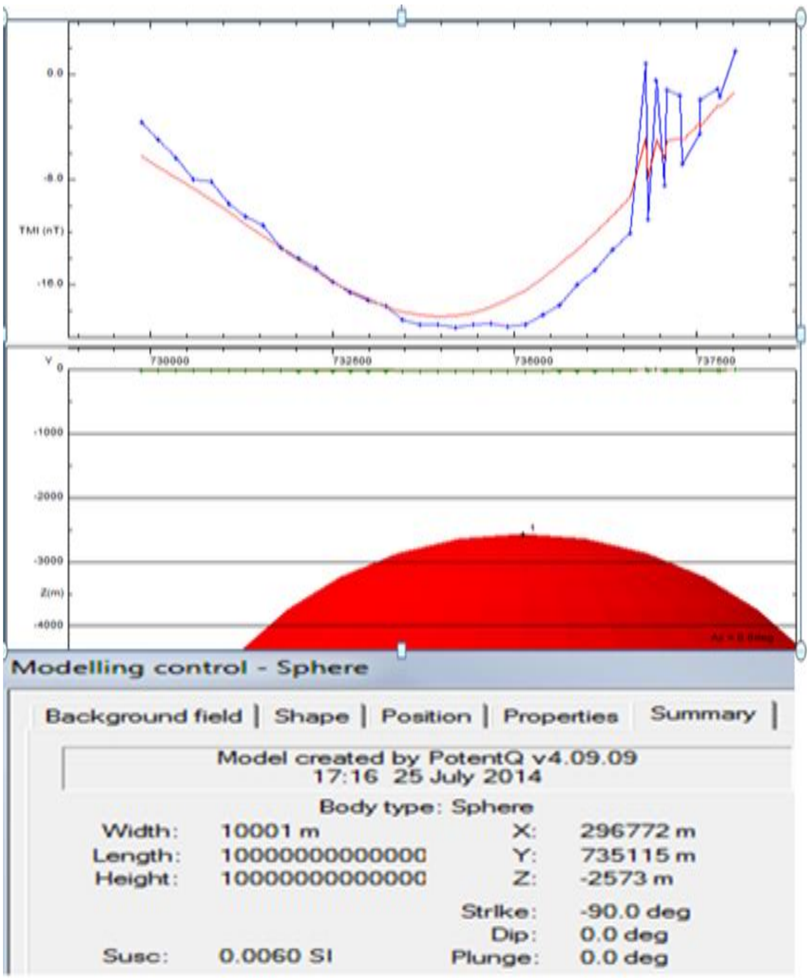


**Figure 7b:** Profile model for B

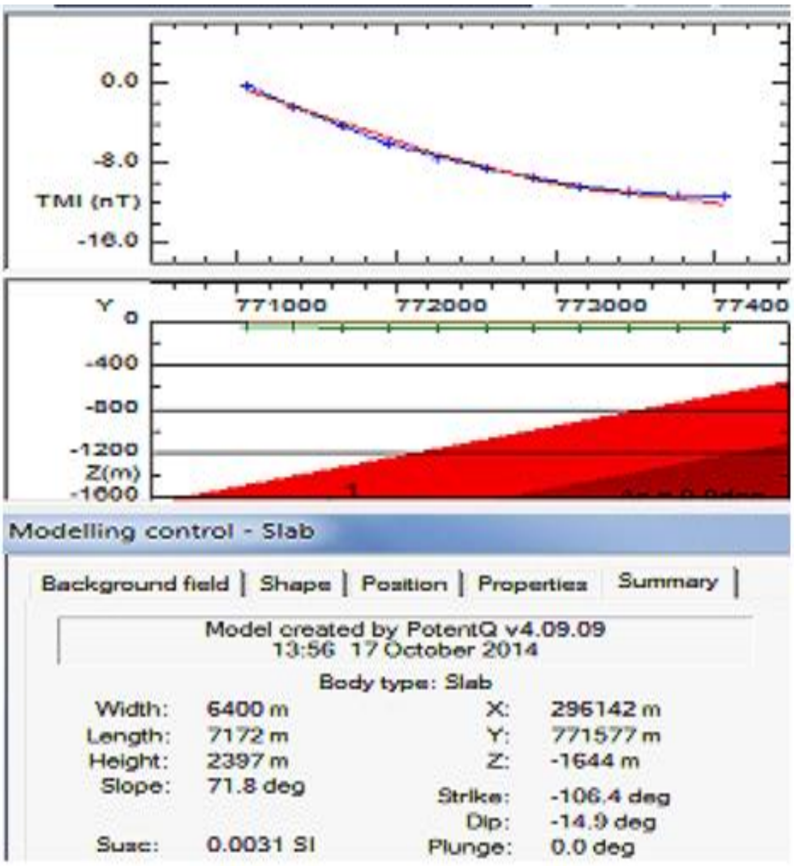


**Figure 7c:** Profile model for C

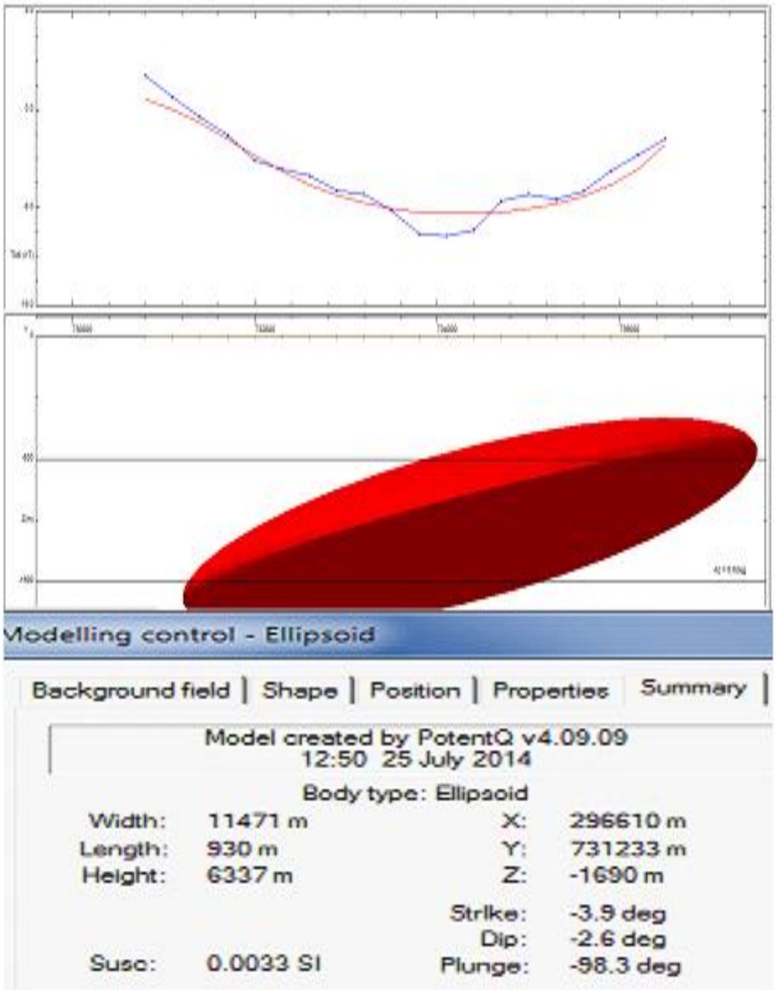


**Figure 7d:** Profile model for D

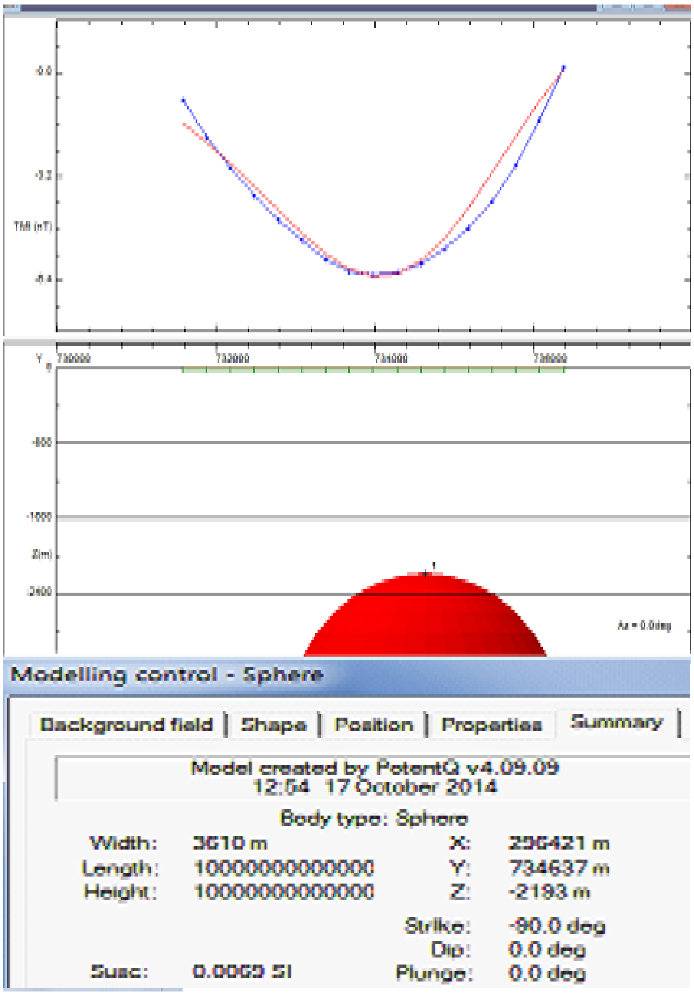


**Figure 7e:** Profile model for E

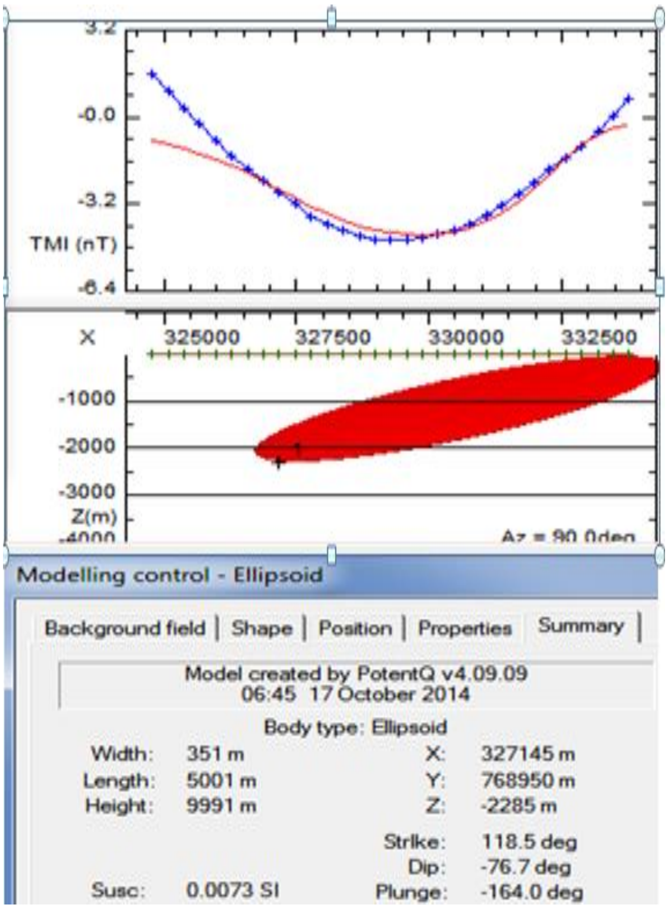


**Figure 7f:** Profile model for F

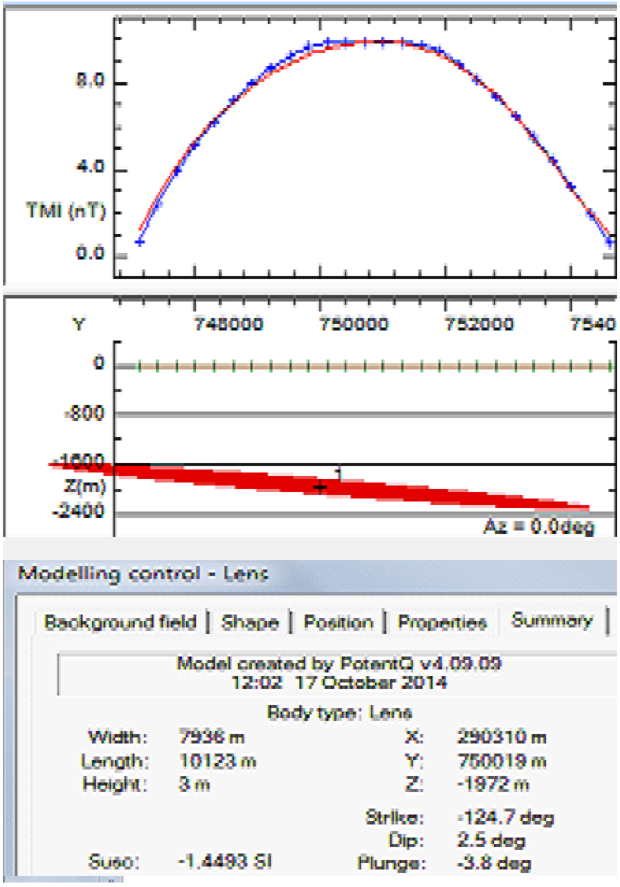


**Figure 7g:** Profile model for G

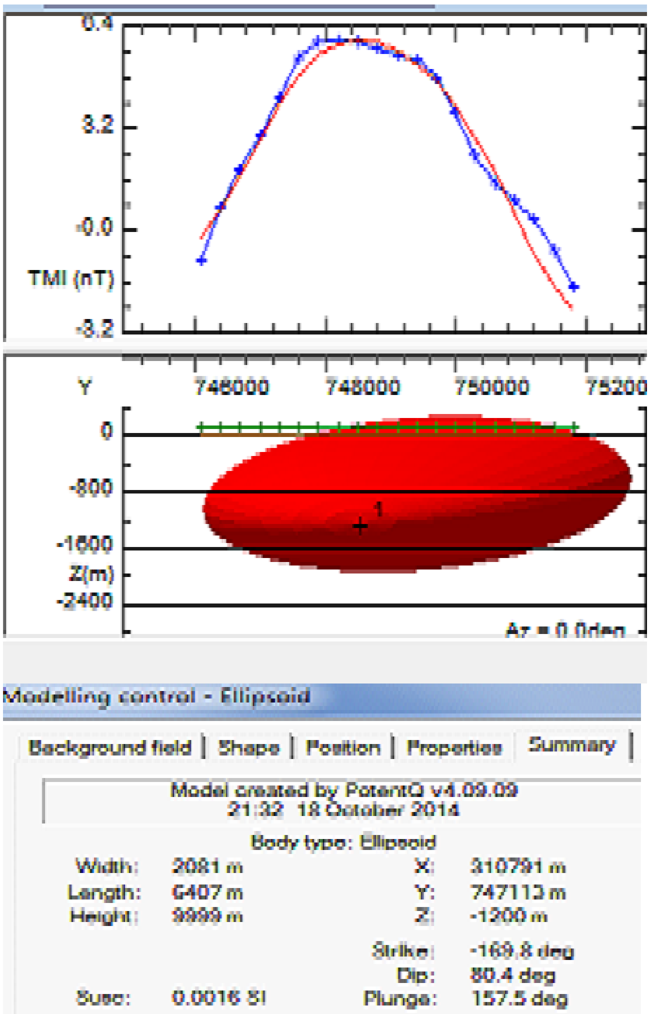


**Figure 7h:** Profile model for H

Eight bodies were modeled and inversion method was performed using the TMI dataset. The Geographic coordinates x, y and z provided by the TMI grid with the field value F of the observed field was used by potent to compare the calculated field values. At the end of each inversion a root mean square value (RMS) is displayed. This RMS is the difference between the calculated and observed field values and in this inversion model, the RMS value is less than 5% and this helped to get an improved result and match between the observed and calculated field.

**Table 1:** Magnetic susceptibilities of some mineral (Telford et al., 1990).

| Rocks | Average Magnetic Suceptibility (SI). |
|---|---|
| Dolomite | 0.00012 |
| Lime Stone | 0.00031 |
| Sands Stone | 0.00038 |
| Shale | 0.00063 |
| Amphibolite | 0.00075 |
| Schist | 0.00126 |
| Quartzite | 0.00440 |
| Slate | 0.00628 |
| Granite | 0.00281 |
| Olivine – Diabase | 0.02513 |
| Diabase | 0.05655 |
| Porphyry | 0.06283 |
| Gabro | 0.07540 |
| Basalt | 0.07540 |
| Diorite | 0.08797 |
| Peridotite | 0.16336 |
| Acidic Igneous | 0.00817 |

**Table 2:** Forward and inverse modeling summary of result.

| Model | X (m) | Y (m) | Depth (m) | Dip (deg) | Plunge (deg) | Strike (deg) | Body shape | K value (SI) | Mineral Present |
|---|---|---|---|---|---|---|---|---|---|
| *A* | *297686* | *770936* | *1087* | *-7.9* | *0.0* | *-123.3* | *Slab* | *0.0037* | *(sandstone)Quartzite* |
| *B* | *327342* | *769428* | *2573* | *0.0* | *0.0* | *-90.0* | *Sphere* | *0.00609* | *(ironstone)Harmatite* |
| *C* | *296142* | *771577* | *1644* | *-14.9* | *0.0* | *-106.4* | *Slab* | *0.0031* | *Quartzite* |
| *D* | 296610 | 731233 | 1690 | -2.6 | -98.3 | -3.9 | Ellipsoid | 0.0033 | (ironstone)Limonite |
| *E* | *296421* | *734637* | *2193* | *0.0* | *0.0* | *-90.0* | *Sphere* | *0.0069* | *Harmatite* |
| *F* | *327145* | *768950* | *2285* | *76.7* | *-164.0* | *118.5* | *Ellipsoid* | *0.0073* | *Harmatite* |
| *G* | *290310* | *750019* | *1972* | *2.5* | *-3.8* | *-124.7* | *Lens* | *1.4493* | *Pyrrhotite* |
| *H* | *310791* | *747113* | *1200* | *80.4* | *157.5* | *-169.8* | *Ellipsoid* | *0.0016* | *Limonite,Pyrite* |

## 8. Conclusion

The magnetic method employed in interpreting this airborne geophysical data in investigating the characteristics of the magnetic anomalous bodies has been described from the survey's findings and an explanation regarding the main magnetic characteristics with respect to the kinds of plausible geological structures and formations that are responsible for the obvious abnormalities has proved to be very useful and powerful in solving the existing problems of detecting magnetic bodies and their depth of burial in the area. It has equally thrown more light to the understanding and applications of scientific knowledge in evaluation of susceptibility properties of magnetic materials beneath the earth surface and contributes highly to delineate of the position, shape and depth of such anomalies in the study area. Fourier transforms used in fixing particular abnormalities when executing an upward or downward continuation and adjusting the effective field inclination (reduction to pole), converting the total field data to vertical-component data, calculating derivatives, data filtering and separating anomalies has showcased its usefulness in solving the problems triggered by sources varying in size and depth of anomalies during modeling. From the results of this work, the depth status of the magnetic anomalous bodies have been rated to be thick sediment (1200 m to 3082.7 m) for the buildup of hydrocarbons, the deposit of minerals, and the start of oil creation from marine organic remnants. This work also revealed shallow depths of 35 m to 150 m which are evident of excellent prospective water sources and give information that will be very important in mineral exploration and management for economic growth in the area.

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## Data Availability

The data used in this manuscript will be made available if requested for.

## Declarations Competing Interests

The authors declare no competing interests.

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## Compliance With Ethical Standards

No animals were used for this research; hence the research work complied with ethical standard.

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