International Journal of Earth Sciences Knowledge and Applications
journal homepage: http://www.ijeska.com/index.php/ijeska
e-ISSN: 2687-5993

Research Article https://doi.org/10.5281/zenodo.17021283

Determination of Depth to Magnetic Source from Aeromagnetic Data of Idah, Kogi State Using Euler Deconvolution Technique

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INFORMATION

Article history
Received 21 July 2025
Revised 31 August 2025
Published 31 August 2025

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How cite
Ayomide, A.A., Ojo, O.F., Blessing, A.M., 2025. Determination of Depth to Magnetic Source from Aeromagnetic Data of Idah, Kogi State Using Euler Deconvolution Technique. International Journal of Earth Sciences Knowledge and Applications 7 (2), 223-231. https://doi.org/10.5281/zenodo.17021283.

Abstract
This study focuses on the application of Euler deconvolution to Aeromagnetic Data collected in the Idah area of Kogi State, located in the North Central region of Nigeria. The research employs Euler deconvolution, a widely recognized technique in the field of geophysics, to determine the depths to magnetic sources within Idah and its surrounding areas. The methodology encompasses a series of systematic steps. Initially, the aeromagnetic data, specifically from Idah (sheet 267) undergoes preprocessing to eliminate noise and enhance the signal. Several filtering techniques, including Regional-Residual separation, Reduction to magnetic equator, and Upward continuation, are employed for this purpose. The study uses Euler deconvolution to identify potential magnetic sources in Idah, Kogi State, and calculates their depths, considering magnetic field anomalies. The results are interpreted within the geological framework. Notably, the Euler solutions for structural indices ranging from 1.0 to 3.0 reveal varying depth ranges, spanning from depths less than 1000 meters to depths exceeding 11000 meters. These solutions are spatially distributed across the region, with distinct clusters corresponding to specific structural indices. For instance, solutions with a structural index of 1.0 are concentrated predominantly in the Northwestern, Western, and Northeastern parts of the map, with limited occurrences in the Southwestern region. The study reveals that solutions with a 2.0 structural index are more concentrated in the Northwestern and central areas of the map, while those with a 3.0 index are primarily clustered in these areas. A quick and precise identification of the positions and depths of magnetic sources within the study area is made possible by the interpretation of the data from the various structural indices, which greatly advances our knowledge of the geological characteristics and possible subsurface resources of the area.

Keywords
Aeromagnetic map, euler deconvolution, magnetic sources, structural indicators, magnetic source depth

1. Introduction

Measurements at or close to the Earth's surface are part of geophysical investigations into the planet's interior, and they are impacted by the distribution of internal physical characteristics. The vertical and lateral changes in the physical characteristics of the Earth's interior can be revealed by analyzing these observations. (Kearey et al., 1991). Various geophysical methods are utilized for subsurface mapping, including Electrical Resistivity, Induced Polarization, Self-Potential, Electromagnetic, Gravity, Magnetic, Radiometric, and Seismic techniques. These methods and their fundamental principles serve as the foundation for mineral exploration and other economically significant geophysical investigations. Airborne geophysical surveys use Magnetic, Radiometric, and Gravity methods to study Earth's underground environment. While radiometric surveying assesses physical characteristics including conductivity, magnetic susceptibility, and the quantity of radioactive elements, magnetic surveying looks at variations in the Earth's magnetic field. This strategy is essential for the development of technology.

Advanced technologies like airborne surveys are employed in geothermal mapping, engineering projects, land management, and oil and mineral exploration. They identify geophysical properties, identify small shifts, and are efficient for mapping extensive areas and cost-effective regional surveys. One commonly used type of airborne geophysical survey is the aeromagnetic survey, where a magnetometer is deployed on board or towed behind an aircraft. The aircraft flies in a grid-like arrangement to swiftly cover vast areas of the Earth's surface for regional reconnaissance. Aerial aircraft height and line spacing determine the data resolution and survey cost per unit area (Allis, 1990).

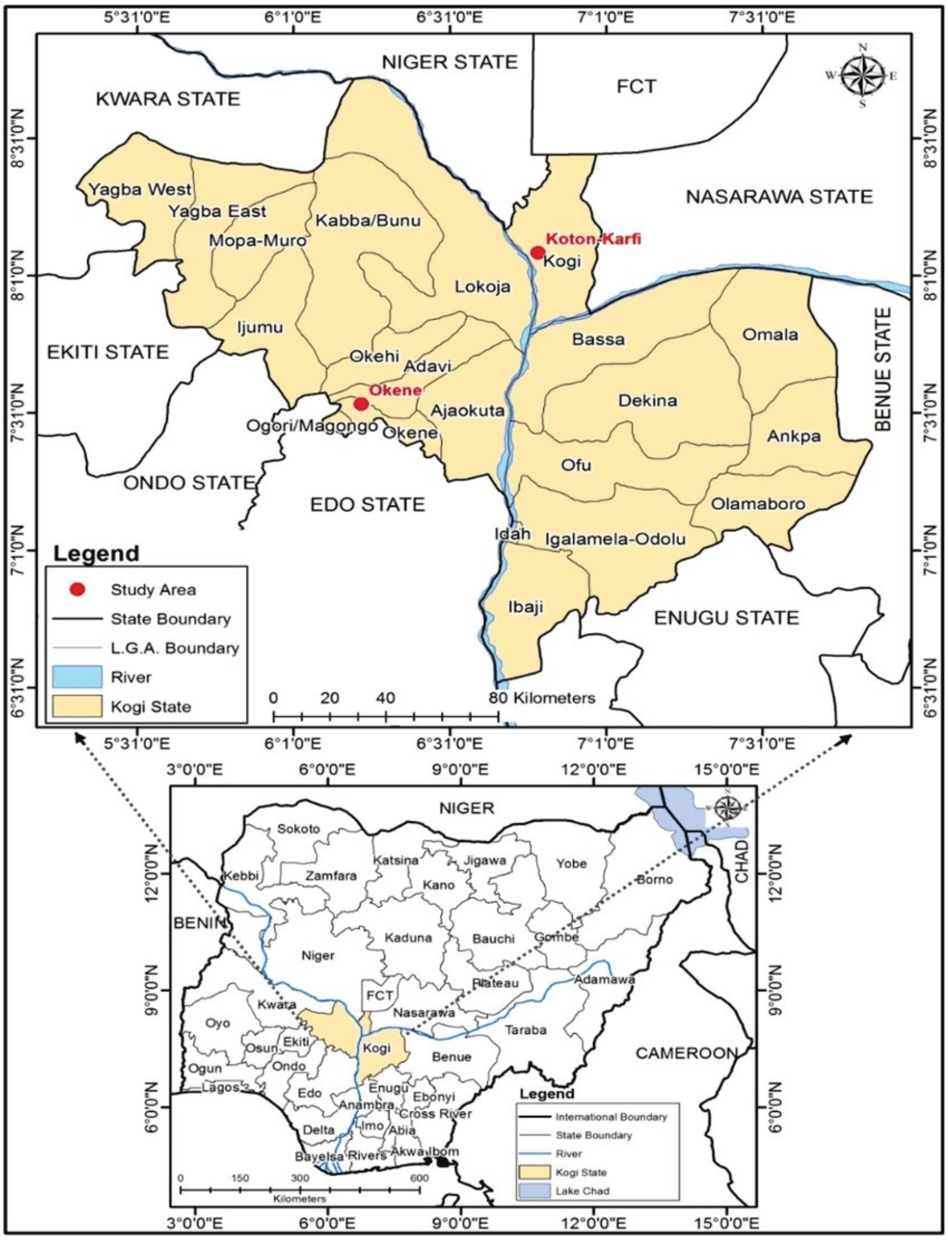

Fig. 1. Kogi state map displaying the study region

The magnetic method is commonly employed to locate buried magnetic materials (Dalan, 2006). Finding the likely depth of the Earth's basement beneath sedimentary rocks is another common use (Salako, 2014). In order to study the subsurface geology, a magnetic survey looks for abnormalities in the Earth's magnetic field that are brought on by the magnetic properties of the underlying rocks. It offers information that is useful for mapping the topography of the basement surface and figuring out how deep the basement rocks are. In order to accurately map and define basement depths and structures, magnetic data is utilized. It is common practice to analyze aeromagnetic data by calculating the locations or depths of the sources. The basement depth can be ascertained by applying the Euler deconvolution methodology to the interpretation of the potential field data, which is now well established (Spector and Grant, 1970).

In this paper, the Euler Deconvolution technique is utilized to determine the depth to magnetic sources Kogi state. This method is useful because it uses gridded magnetic data to automatically determine shallow and deeper source depths.

2. Location and Geology of Study Area

The study area (depicted in Fig. 1) is situated within Kogi State, specifically Idah on the sheet number 267 on the aeromagnetic data sheet, located in the northern-central region of Nigeria. This geographic location is bound by latitude 7° 00' N and 7° 30' N, as well as longitude 6° 00' E and 6° 30' E. The research area is made up of two separate geological components: half of it is located in the basement complex of southwest Nigeria, while another part is in the sedimentary terrain of the Anambra Basin. The Sedimentary Basin and Basement Complex makes up Kogi State, a distinctive geological area. Half the state is covered by the crystalline Basement Complex, and the other half is made up of Cretaceous to Recent sediments. The region's foundation is shaped by Precambrian rocks. The Basement Complex, a significant feature of Kogi State, is a complex of folding, faulting, and metamorphism-influenced rocks, encompassing migmatites, gneisses, granite-gneisses, and schist belts, influencing the state's structural framework. The Basement Complex houses the Pan-African Older Granites, a collection of crystalline rocks rich in valuable minerals such as iron ore, gemstones, quartz, and feldspar. Kogi State, located on the eastern flank of Anambra Basin, is home to sedimentary rocks like alluvium and other formations (Fig. 2). These formations, including the Nkporo, Mamu, Ajali, and Nsukka Formations, influence the distribution of minerals like coal, kaolin, clay, and gemstones.

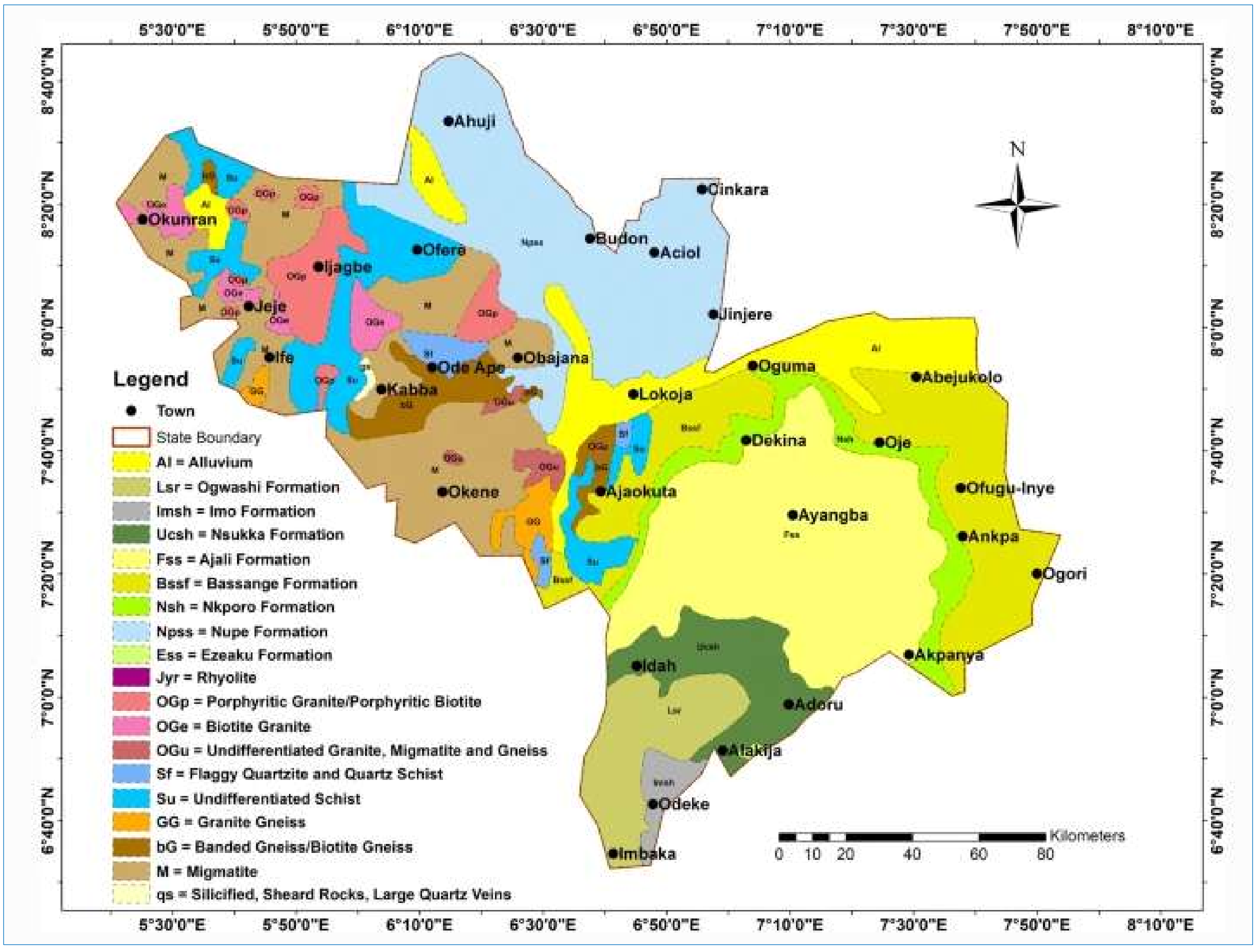

Fig. 2. Kogi State geological map (Modified from NGSA, 2006)

3. Materials and Method

An aeromagnetic grid with sheet numbers 204 with the location called Idah was acquired, assembled and interpreted. In 2009, the grid was acquired as part of a statewide aerial survey conducted by Fugro and funded by the Nigerian Geological Survey Agency. At a height of 100 meters, the data were collected with a tie line spacing 2000 meters and a flight line spacing 500 meters, aligned in a NW-SE direction. Mostly contoured at 10 nT intervals, the maps are half-degree sheets with a 1:100,000 scale.

Using the International Geomagnetic Reference Field

(IGRF), the geomagnetic gradient was eliminated from the data. Aeromagnetic surveys were flown at 500 m line spacing and 80 m terrain clearance. The average magnetic inclination and declination across the survey area was -11.443° and -0.505° respectively. The geomagnetic gradient was removed from the data using International Geomagnetic Reference Field (IGRF) and the data was collected in digitized form (X Y Z). The X and Y represent the longitude and latitude respectively in meters, Z represents the magnetic intensity measured in nano Tesla (nT).

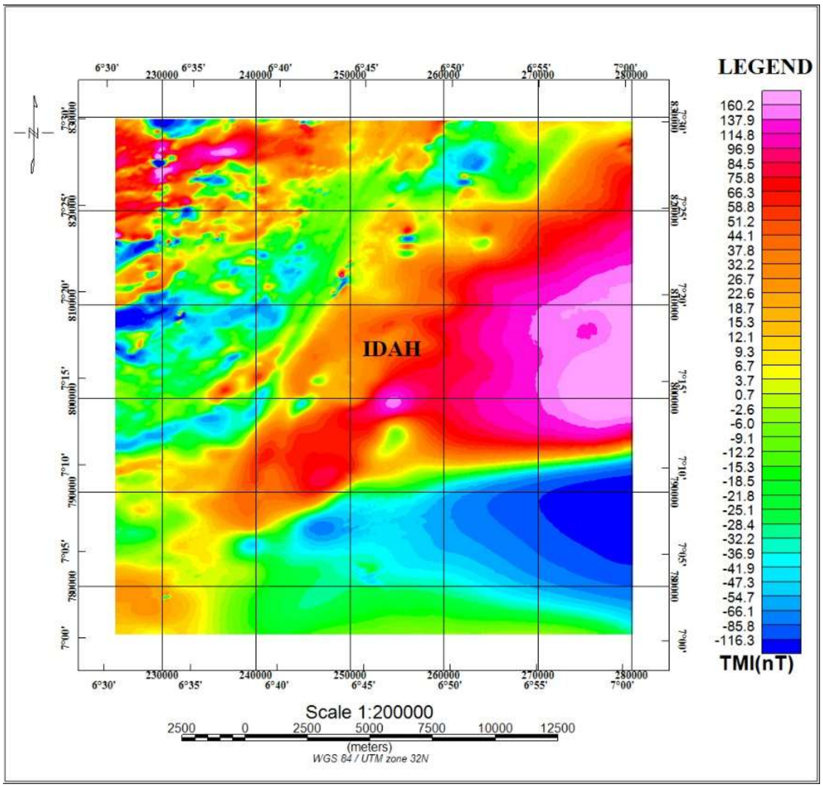

Fig. 3. The Map of Total Magnetic Intensity (TMI)

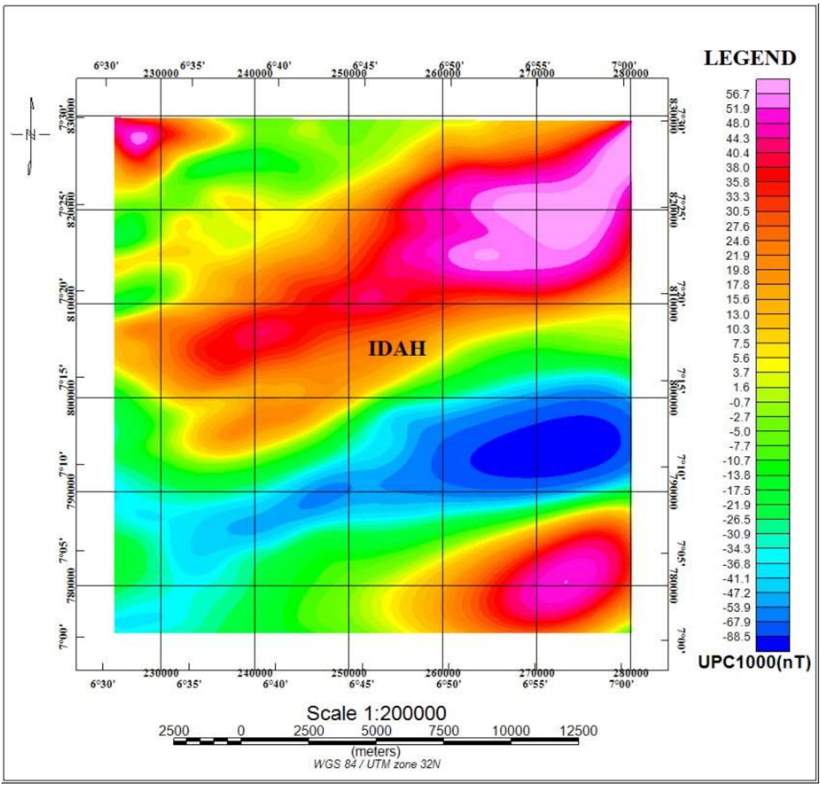

Fig. 4. Upward Continuation Map at 1000 Meters

4. Data Processing and Interpretation

4.1. Magnetic Data

Filtering techniques improve data quality by eliminating undesirable features, and polynomial fitting is used to separate the total magnetic intensity regionally and residually. The total magnetic intensity map (TMI) of the research area was created by re-gridding the map that covered it using Oasis Montaj software (Fig. 3). A total magnetic intensity of -160.2 nT to 116.3 nT was found in the study area.

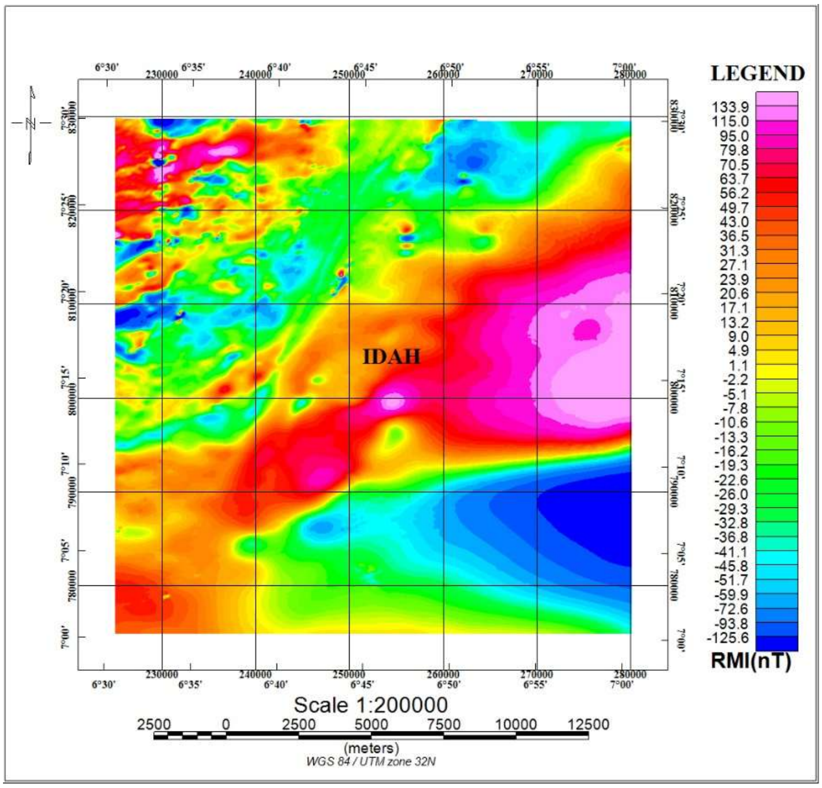

Fig. 5. Regional-Residual Separation Map

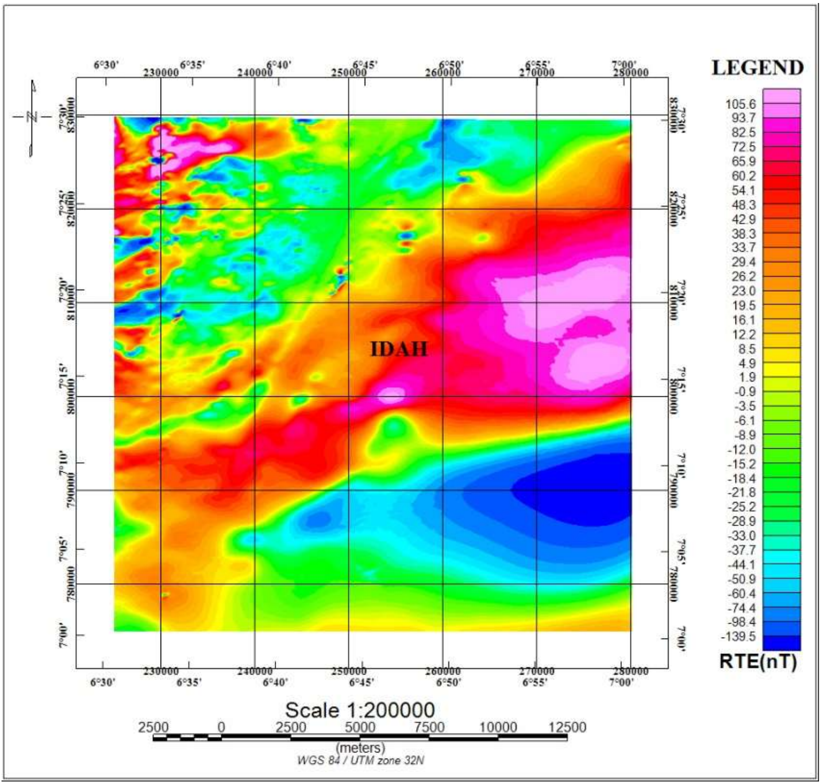

Fig. 6. Reduction to Magnetic Equator Map

The digitized aeromagnetic data of Idah, Kogi state, and its surroundings were subjected to the following treatments after the creation of the Total Magnetic Field Intensity Map. This allowed for the quantitative calculation of the depth to magnetic sources using the Euler Deconvolution technique. The study area's overall magnetic strength map was created into color aggregate maps (Fig. 3).

From a minimum of -116.3 nT to a maximum of 160.2 nT, the area's magnetic intensity varies. Both high and low magnetic signatures are present in the region, which may be caused by a number of variables, including depth variation, lithological differences, magnetic susceptibility differences, and strike intensity. In the center of the maps that trend northeast of the research area, these high magnetic anomalies are more noticeable. A small number of these anomalies are also discernible in the region's N-W and S-E regions. The low magnetic anomalies all trend in a NW-SE direction and are most noticeable in the southern and western regions of the region, with only a small number observed in the northern region

4.1.3. Upward Continuation

In an effort to refine the field data prior to calculating the depth to the magnetic source using the Euler Deconvolution technique, the grid that was derived near the magnetic equator was extended vertically from a height of 100 meters, 500 meters and then to a height of 1000 meters. Upward continuation is a magnetic filter that aids in the attenuation of shallow magnetic structure with the primary aim of enhancing the deep lying magnetic anomalies that are of great significance in data interpretation. The resulting grid of the upward continuation process was employed to produce the upward continuation map of the study area. At upward continuation of height 1000 meters (Fig. 4), this map gave a range of magnetic field intensity value ranging from -88.5 to 56.7 nT. At this upward continued depth, there is still evidence of the prominence of the highly magnetized materials in the eastern and minimal on the Northwestern part of the study area while the magnetic field intensity values still reduce southwards.

4.1.1. Regional-Residual Separation

The Total Magnetic Intensity data (observed data) underwent a process where the regional magnetic field was eliminated by fitting first-order polynomials with the OASIS MONTAJ program. The resulting residual grid data was then transformed into a magnetic map (Fig. 5), displaying magnetic intensities spanning from -125.6 nT to 133.9 nT. The dominance of magnetic entities exhibiting strong intensity in the eastern section and minimum in the central, northwest and southeast of the study region remained conspicuous within the Residual Magnetic Intensity data.

4.1.2. Reduction to Magnetic Equator

The anomaly map that resulted from the process of separating the regional-residual magnetic field was adjusted to align with the magnetic equator. This adjustment was necessary because Nigeria is situated in a part of the world with a low latitude. To accomplish this, the leftover magnetic data specific to the study area was aligned with the magnetic equator using the magnetic angle values that pertain to the middle portion of the study area.

The outcome of the reduction to magnetic equator process, seen in the adjusted anomaly map (Fig. 6), displayed intensity values ranging from -154.0 nT to 106.0 nT. The dominance of regions with strong magnetic field intensity in the eastern and little on the Northwestern and southwestern a section of the research area remained conspicuous on the RTE grid map, as the magnetic field intensity decreased towards the south.

4.1.4. Euler Deconvolution of Aeromagnetic Data

Reid *et al.* (1990) described the Euler deconvolution technique, which uses Euler's homogeneity relation to deconvolution, is a useful tool in potential field analysis for locating anomalous sources and establishing their depths. Because it does not depend on a particular geological model and provides a quick method for converting magnetic field observations into estimates of the location and depth of magnetic source bodies, this approach has becoming more and more common.

Numerous works by Nwankwo et al. (2016), Nabighian et al. (2005) and Aboud et al. (2003) demonstrate how Euler deconvolution has been applied to total magnetic field data. Its use dates back to Thompson's (1982) work, in which he presented a framework for examining magnetic profiles using Euler's relation for homogeneous functions. According to Nwankwo et al. (2016), this process uses first-order x, y, and z derivatives to determine the position and depth of several idealized targets (such as spheres, cylinders, thin dikes, and contacts), each of which is identified by a unique structural index (Figs. 7-9)

When applied to magnetic field data, Euler's 3D homogeneity relation takes the following form (Reid et al., 1990; Reid 1997):

$$(x-x_0)\frac{\partial T}{\partial x}+(y-y_0)\frac{\partial T}{\partial y}+(z-z_0)\frac{\partial T}{\partial z}=N(B-T) \quad (1)$$

The regional field is B, and the total field magnetic anomaly at the point (x, y, z) is T. The magnetic source is located at (x_0, y_0, z_0). The structural index, or N, is a measure of how quickly a field changes with distance and takes on different values depending on the kind of magnetic source. Calculating or measuring the anomaly gradients for different anomaly areas and choosing a value for N solves the aforementioned equation (Philip et al., 2002). The structural index is the integer exponent of a power law that shows how field intensity decreases with increasing distance from the source. Physically conceivable structural index values for magnetic data fall between 0 (contact of unlimited depth extent) and 3 (point dipole). A field strength that rises with distance from the source (and is infinite at infinity) is indicated by values smaller than 0. Quadruple or higher-order multiple sources are indicated by values larger than 3. The SI value is crucial because if it is used incorrectly, deceptive depths can occasionally be calculated with errors greater than double the depth.

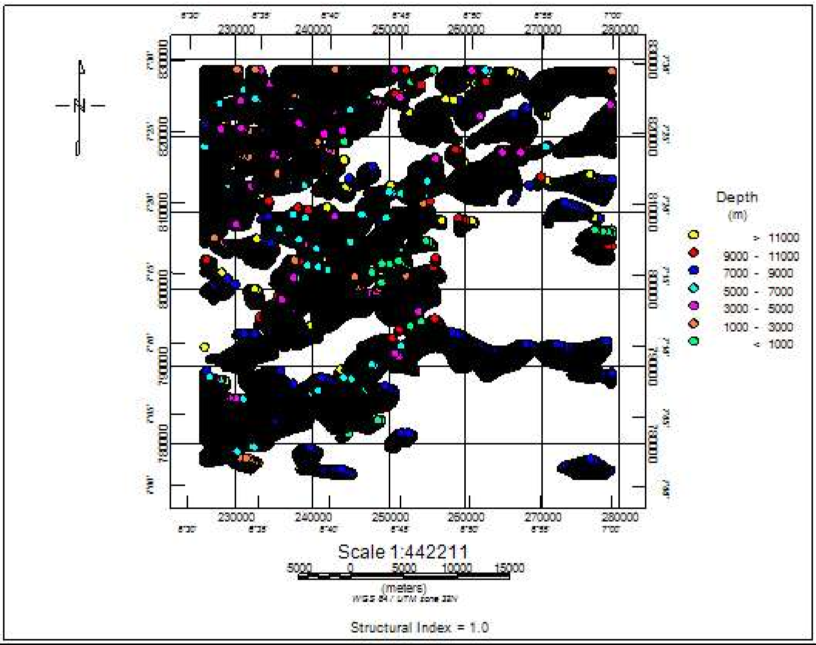

Fig. 7. The research area's Euler Deconvolution Depth Plot for S.I = 1.0

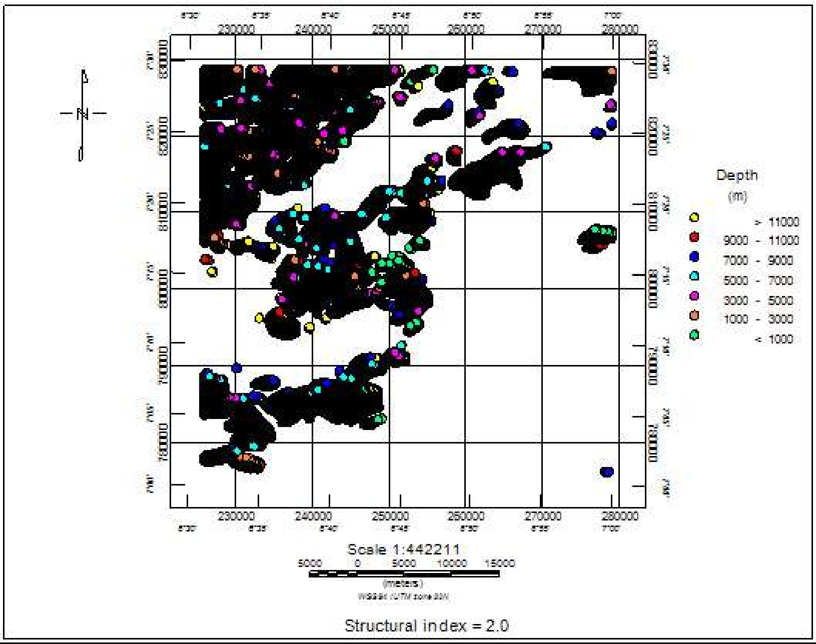

Fig. 8: The research area's Euler Deconvolution Depth Plot for S.I = 2.0

4.2. Depth Estimation

Figs. 7-9 display the generated Euler-3D grid picture and Euler-3D legends for structural index 1.0, 2.0, and 3.0. The value numbers on the legend indicate depth, and the varying colors represent the contrast of different magnetic susceptibilities within the research area. With depth to magnetic source values ranging from less than 1000 meters to more than 11,000 meters, the three figures above display the results of Euler solutions for structural index 1.0, 2.0, and 3.0 of the magnetic anomalies over the research area.

These solutions are dispersed geographically over the area, with certain structural indices correlating to different clusters. Solutions with a structural index of 1.0, for example, are primarily found in the Northwestern, Western, and Northeastern regions of the map, with a small number occurring in the Southwest. Solutions with a structural index of 2.0, on the other hand, are more concentrated in the middle and northwest sections of the map, while they are less prevalent in the southwest and northeast. The middle and northwest regions of the map are where solutions with a structural index of 3.0 are most concentrated.

Euler Deconvolution displays the depth solutions as they appear on the maps; regions that are deeper than 5000 meters are shown in red, yellow, blue, and sky blue. Conversely, brown, purple, and green indicate depths that are shallower (<5000 m).

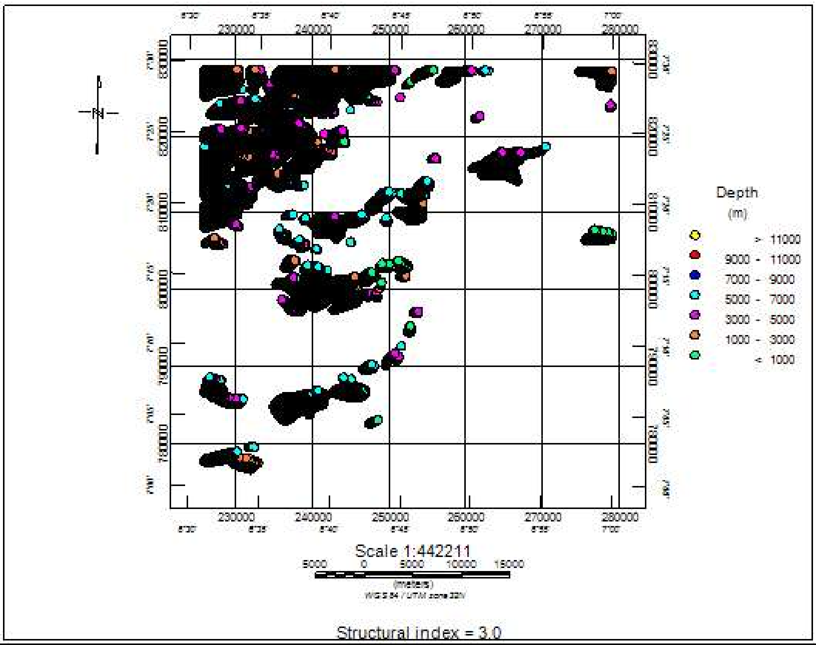

Fig. 9. The research area's Euler Deconvolution Depth Plot for S.I = 3.0

5. Conclusion

The Euler deconvolution method was used to analyze aeromagnetic data (sheet 267) from the Idah region in north-central Nigeria. The cluster solutions, represented by circles, lined up with the research area's Total Magnetic Intensity map. We estimated the depth to magnetic sources using the 3D Euler deconvolution technique. Quantitatively, the findings showed that the depths of anomalous sources ranged from less than 1000 meters to more than 11,000 meters. A visual representation of how different magnetic filters affect the dataset may be found. Our knowledge of the magnetic features in the region is further enhanced by the Reduction to Magnetic Equator and Upward Continuation maps, which offer more details on the spatial distribution of magnetic field intensities. The Residual Magnetic Intensity also reveals clear intensity patterns throughout the study area. When the structural index (SI) was calculated using Euler deconvolution, the depths for SI values of 1.0, 2.0, and 3.0 ranged from less than 1000 meters to more than 11,000 meters in relation to the magnetic source. Using various colors, the depth solutions produced by Euler deconvolution were displayed on the map. Green, purple, and brown hues denoted shallower depths, less than 5000 meters, while tones of red, yellow, blue, and sky blue marked deeper regions, exceeding 5000 meters.

6. Recommendation

Based on the results obtained from this research, the following is recommended: Another imaging techniques like Electrical Resistivity method should be employed to strengthen the observations made in this research. Other techniques like Source Parameter imaging, and Spectral analysis can be carried out on the Idah aeromagnetic sheet.

Acknowledgement

The authors appreciate the Nigerian Geological Survey Agency, Abuja Nigeria for providing the aeromagnetic data for this research. The opinions presented in this work are based on the writers' combined experiences from the research. There is little question that the writers may have overlooked some important ideas. We are solely accountable for any bias or omission.

Conflict of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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