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Geophysical Interpretation of Obudu Area, Cross River State, Southeastern Nigeria Using Aeromagnetic Data

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Abstract

In order to identify the boundaries and intersections of linear geological features within the study region, the aeromagnetic data obtained from the Obudu area in southeast Nigeria was enhanced using precise methodologies, such as the Horizontal derivative (HD), first vertical derivative (FVD), and second vertical derivative (SVD). The process of separating the regional and residual aeromagnetic data information involved applying the polynomial fitting algorithm prior to filtering. The depth to magnetic sources was estimated using the usual Euler deconvolution approach. The studied area is characterized by fluctuations in aeromagnetic signals, indicating alterations in the magnetic susceptibilities of the underlying sedimentary and basement rocks based on the available information derived from the interpreted data. The filtered aeromagnetic maps may exhibit lineaments that exhibit movement along the NE-SW and NW-SE directions. The depths at which anomalies arise from structural complexities were assessed by Euler configurations within the vertical range of 0 to 2100 meters. The presence of a low sedimentation thickness and a high density of lineaments within the studied area suggests a potential correlation between the identified geological formations and hydrothermal mineralization.

Keywords

Aeromagnetism, Euler Deconvolution, Mineralization, Obudu, Magnetic Intensity

Introduction

Over the past few decades, there has been a shift in the interpretation of airborne magnetic maps, moving away from a primary focus on basement structures towards a more comprehensive examination of structures and lithological variations within the sedimentary layer. The sedimentary basins are underlain by a collection of rocks referred to as the magnetic basement, which occasionally becomes exposed at the surface. The mapping of the shape and structure of the basin floor can be achieved by locating the magnetic units present at the surface of the basement. The presence of magnetic anomalies across multiple sedimentary layers can be attributed to secondary mineralization occurring along fault lines, which are frequently observed as linear features on aeromagnetic maps. The majority of theories regarding ore genesis and concentration make use of tectonic or deformational ideas. Most mineral formations are commonly linked to lithospheric deformation. It has been discovered that specific lineament patterns are the most conducive structural conditions for regulating various mineral deposits. These structures are composed of the remnants of prominent regional lineaments, the points at which major lineaments connect, as well as tensional lineaments. These lineaments can be either major (regional) or local in nature. The magnetic properties inherent to our globe enable earth scientists to explore a diverse array of magnetic applications. In order to gain an understanding of the magnetic properties exhibited by Earth's materials, it is essential to possess a foundational knowledge of the principles underlying magnetism (Dobrin & Savit, 1988). The aforementioned essential concepts form the basis for the use of magnetic principles in the field of mineral, oil, and gas exploration. The magnetic susceptibility, or the intrinsic magnetism of rocks, is influenced by alterations in the underlying geologic formations. The magnetic susceptibility of rocks plays a crucial role in magnetic applications utilized in the field of oil and gas exploration. The susceptibility of a rock unit to seismic activity is consistently defined by its magnetite (Fe_3O_4) content. Magnetic susceptibility, like density in gravity interpretation, plays a crucial role in magnetics. Notably, magnetic susceptibility can be expressed as a range, even for a particular type of rock. Magnetic prospecting, which represents the first method of geophysical exploration, is thus crucial in delineating the area and positioning of Sedimentary Basins. According to Ekwok et al. (2020), it may be inferred that the research area is characterized by significant long and minor short-wavelength discontinuity zones resulting from the intrusion of magmatic materials. These intrusive and Precambrian basement rocks are observed either at the Earth's surface or concealed beneath relatively shallow sedimentary layers ranging from around 151 to 745 meters in thickness. A comprehensive area examination was conducted using an aeromagnetic intensity contour map. The analysis of the total magnetic intensity map and residual magnetic intensity map of the region revealed a complex array of magnetic anomalies characterized by a combination of long and short wavelengths. Regions exhibiting high magnetic intensity values are indicative of pre-Cambrian basement or intra-basement intrusions with a basic configuration (Innocent et al., 2019; Arinze et al., 2018).

Magnetic surveying is one of the earliest geophysical techniques employed in scientific investigations. The utilization of this technique was initially documented in Sweden in the year 1640, with the primary objective of locating deposits of magnetic iron ores. The advent of technologies designed to quantify the Earth's magnetic field during the 1880s led to a notable rise in the utilization of magnetic surveys for the purpose of mineral prospecting. During the initial surveys, a limited number of tiny areas were subject to comprehensive examination, wherein magnetometer readings were collected in close proximity to or directly on the Earth's surface. The rapid expansion of magnetic surveys in terms of quantity and coverage area was facilitated by implementing an aircraft-mounted magnetometer instrument, originally developed for submarine detection in World War II. In 1945, the U.S. Geological Survey and the U.S. Navy conducted the inaugural airborne magnetic survey, also known as an aeromagnetic survey, in the region of Alaska. This initiative was driven by geological considerations. Towards the conclusion of the 1940s, individuals commenced engaging in global air travel to conduct aeromagnetic surveys.

The primary objective of this study is to investigate the magnetic characteristics of the Obudu area and its neighboring regions to provide a comprehensive analysis of the geophysical data obtained from the Obudu region. The aeromagnetic survey technique is employed to assess the magnetic susceptibility of nearby rock formations, infer the possible presence of mineral deposits within the region, and determine the depth of anomalous bodies. Figures 1 and 2 illustrate the spatial representation of the research region, providing an overview of its geographical location. On the other hand, Figure 3 presents a visual representation of the geological characteristics of the research area.

Fig. 1. Map of Nigeria showing Cross River State

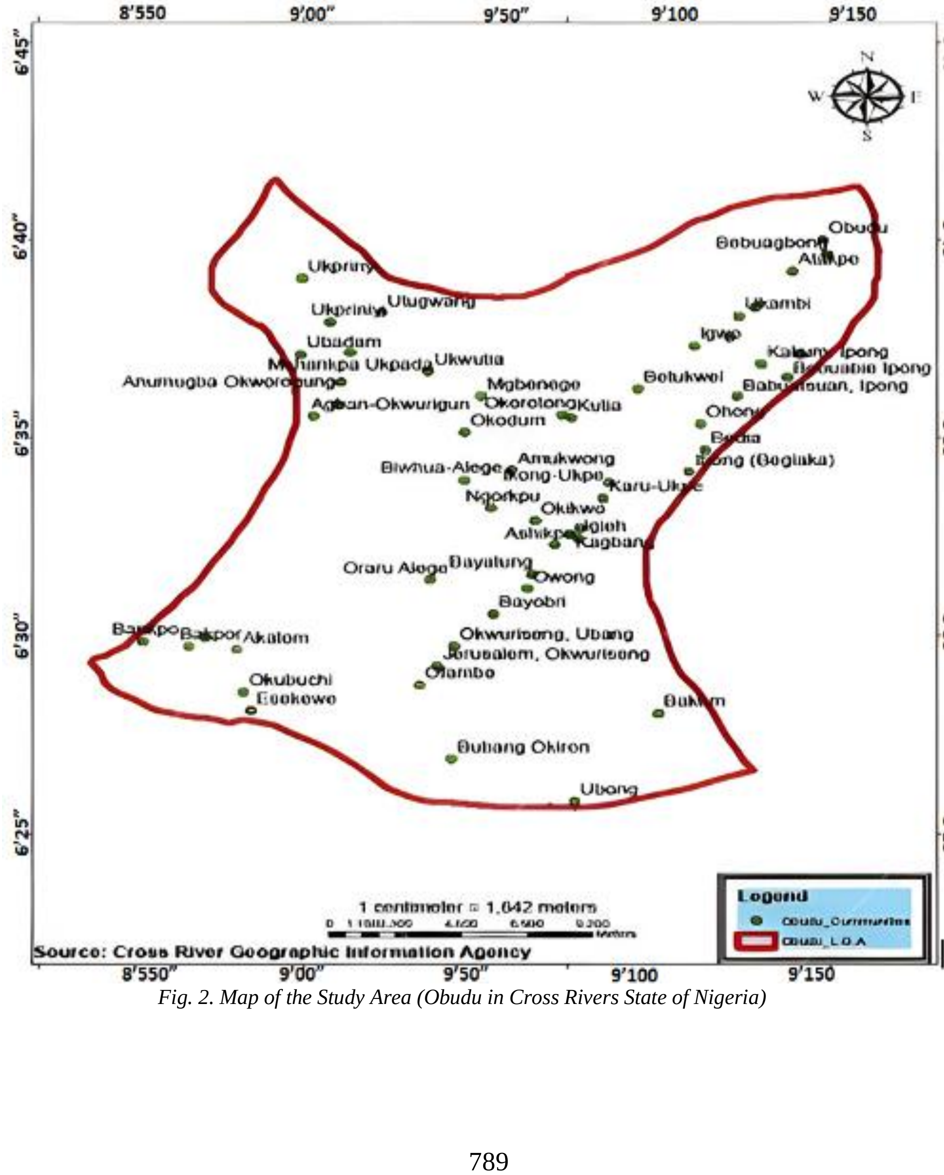

Fig. 2. Map of the Study Area (Obudu in Cross Rivers State of Nigeria)

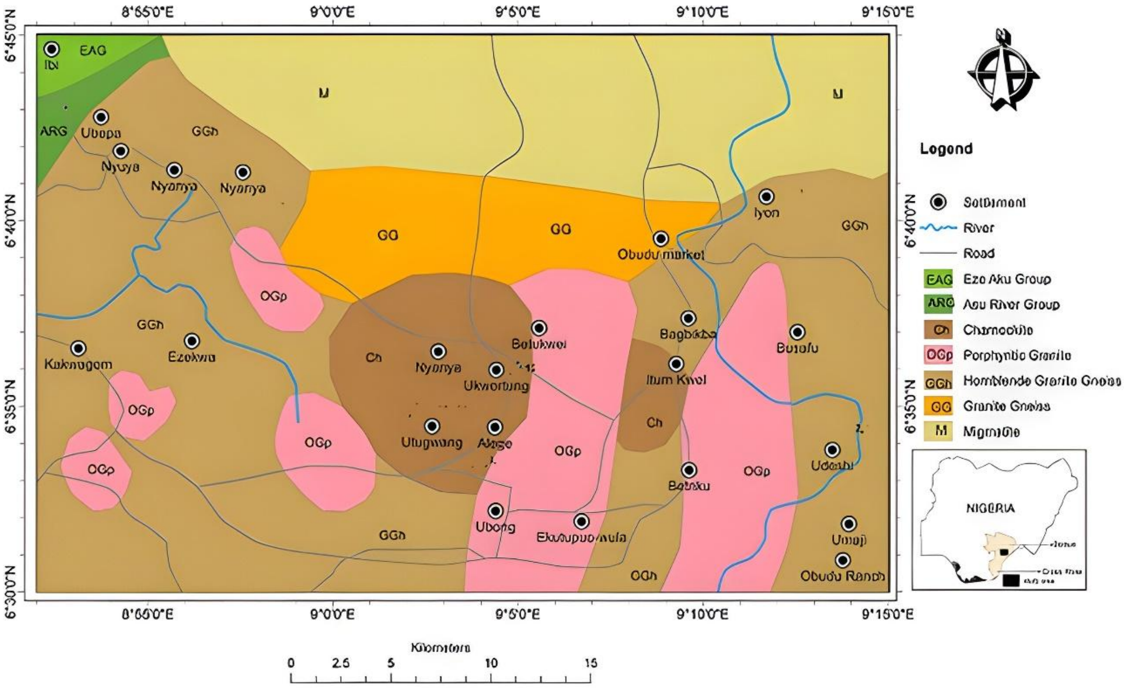

Fig. 3. Geological Map of Obudu and Environs.

Materials and Methods

The specific location and temporal parameters of these recorded data, along with corresponding magnetic field measurements, were established. The collection and storage of data pertaining to magnetic, navigational, temporal, altitude, and aircraft attitude parameters were carried out utilizing a modern data acquisition system, frequently relying on computer technology. Furthermore, the researchers obtained video records documenting the trajectory of the aircraft. Subsequently, these recordings were employed to identify magnetic disturbances caused by human-made objects and verify the navigation system's accuracy. The precise synchronization of all data streams was necessary to process the raw magnetometer data.

Examining aerial magnetic data involved implementing techniques such as airborne magnetic data filtration, regional-residual separation, and depth estimate analysis. Magnetic data filtration was accomplished by identifying and enhancing abnormal properties associated with a specific wavelength, hence enabling the separation of signals with different wavelengths. The process of Regional-Residual separation was successfully achieved by conducting a meticulous analysis of the potential field profile, both within and outside the local area of interest depicted on the map. Depth estimation analysis was conducted using Euler Deconvolution and the first vertical derivative data.

Results and Discussion

Total Magnetic Intensity (TMI) Map

Figure 4 depicts the total magnetic map (TMI) map of the designated research area. The map exhibits the heterogeneity in the magnetic characteristics of the underlying rocks within the study area. The anomalies observed in this study exhibited varying degrees of magnitude, ranging from high to low, with some falling within the intermediate range. Notably, these anomalies displayed a distinct pattern, primarily oriented in the NE-SW and NW-SE directions. The TMI map exhibits a prevalence of high anomaly values ranging from 46.0 to 147.0nT in the northern, northeastern, and southwestern regions. Conversely, the western and southern regions are characterized by a prevalence of low anomaly values ranging from -122.9 to 2.6nT. The intermediate anomalies (8.3 - 35.2nT) are observed in the central and southeastern portions of the map. The aeromagnetic signatures observed in the region are indicative of the magnetic influences exerted by anomalous sources of varying wavelengths beneath the Earth's surface. These signatures are closely associated with significant geological processes. The anomalies (faults) may have sharp magnetic boundaries characterized by vertical or steeply dipping contacts. The examined region frequently exhibits distinct aeromagnetic signatures characterized by notable abnormal features of varying magnitudes and dimensions, which closely align with the underlying basement structure.

Regional Anomaly Maps

The initial to subsequent regional anomaly maps of the Obudu region were generated by applying polynomial fitting techniques on the total magnetic intensity grid. The foundation of this strategy is established by the analytical least squares method and the polynomial decomposition series. Utilizing the least-square method, as outlined in many scholarly works (Gupta, 1983; Murthy, 1990; Nguimbous-Kouoh, 2010), a numerical surface was computed to optimize the alignment of the magnetic field within defined boundaries. The created surface is referred to as a regional oddity. The residual magnetic field is obtained by subtracting the observed magnetic field from the regional magnetic field. The regional surface is commonly regarded as a bivariate polynomial with two layers. The arrangement of this polynomial is contingent upon the intricacy of the geological characteristics present within the studied region. Figures 5, 6, 7, and 8 illustrate the polynomial surfaces of the regional anomaly identified in this work, ranging from first to fourth order.

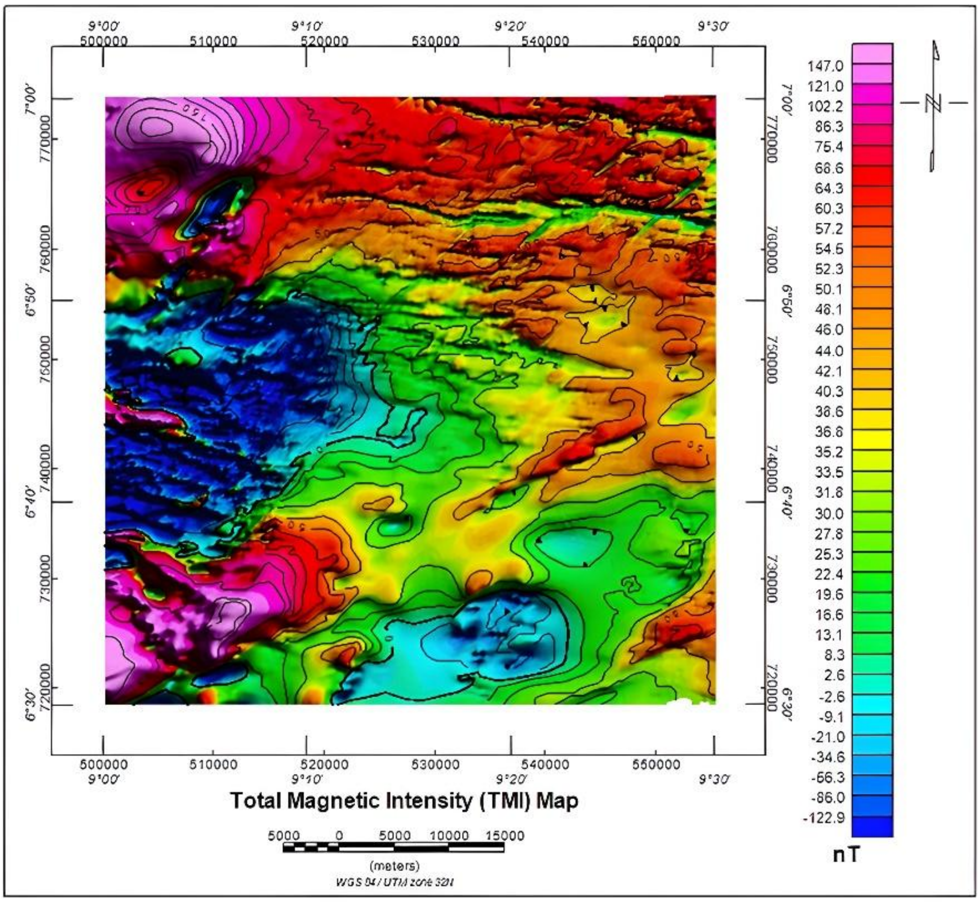

Fig. 4. Colour-shaded Total Magnetic Intensity Map of the Study area.

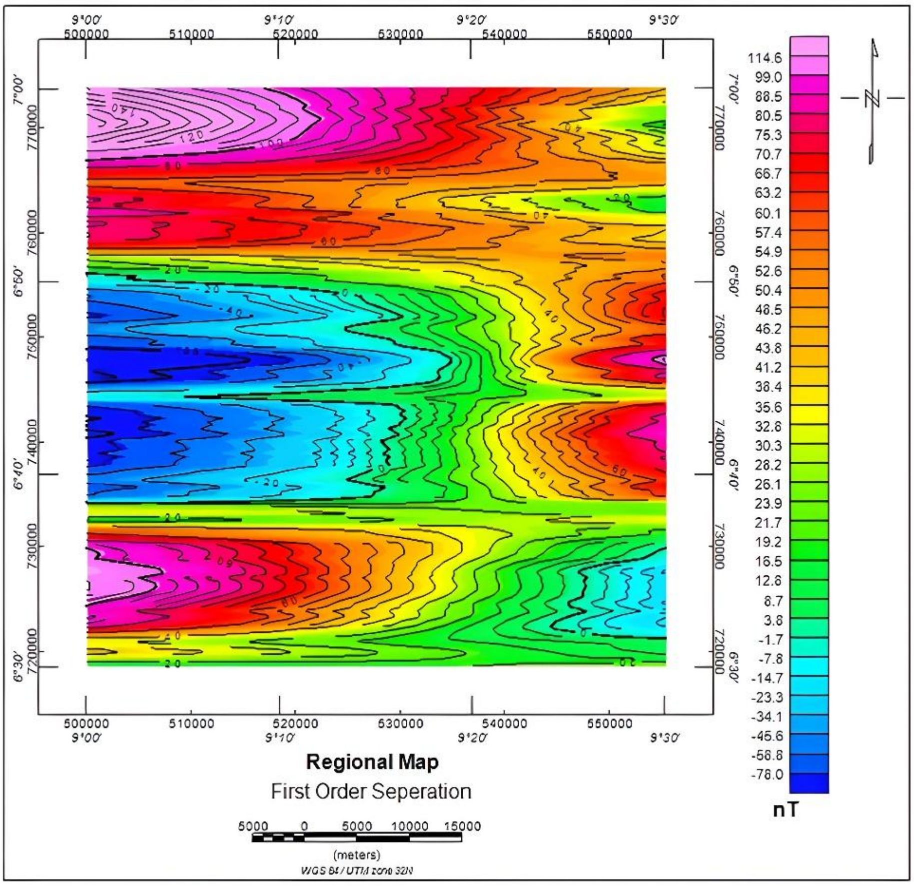

Fig. 5. First Order Regional Map of the Study area.

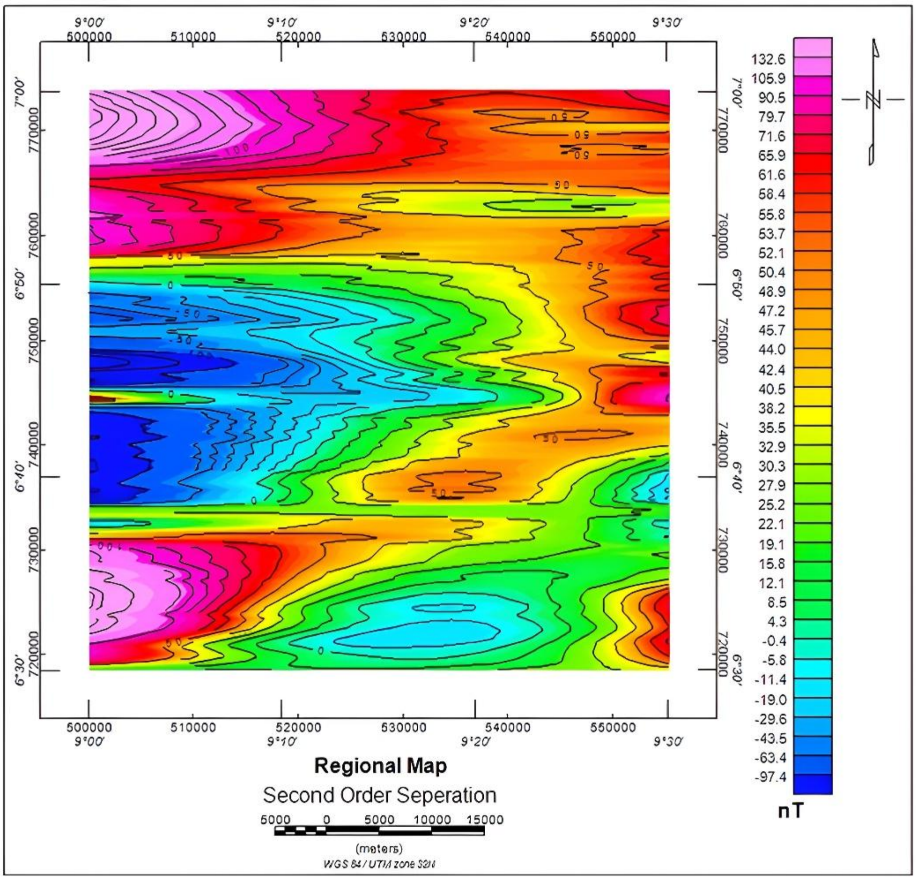

Fig. 6. Second Order Regional Map of the Study area

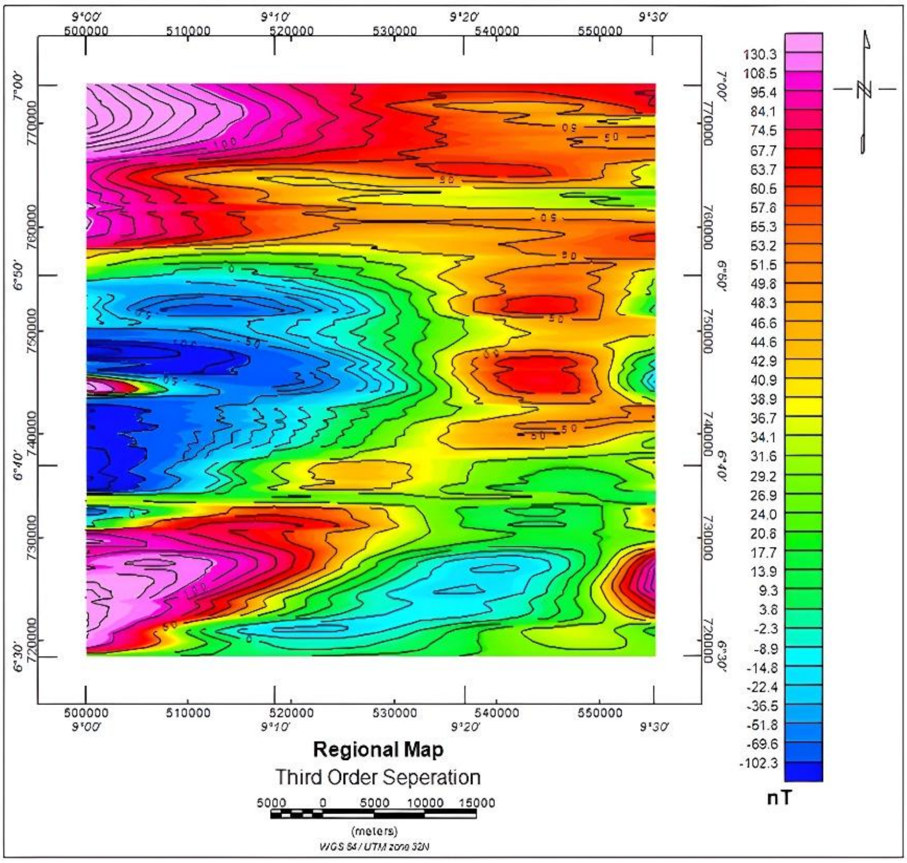

Fig. 7. Third Order Regional Map of the Study area.

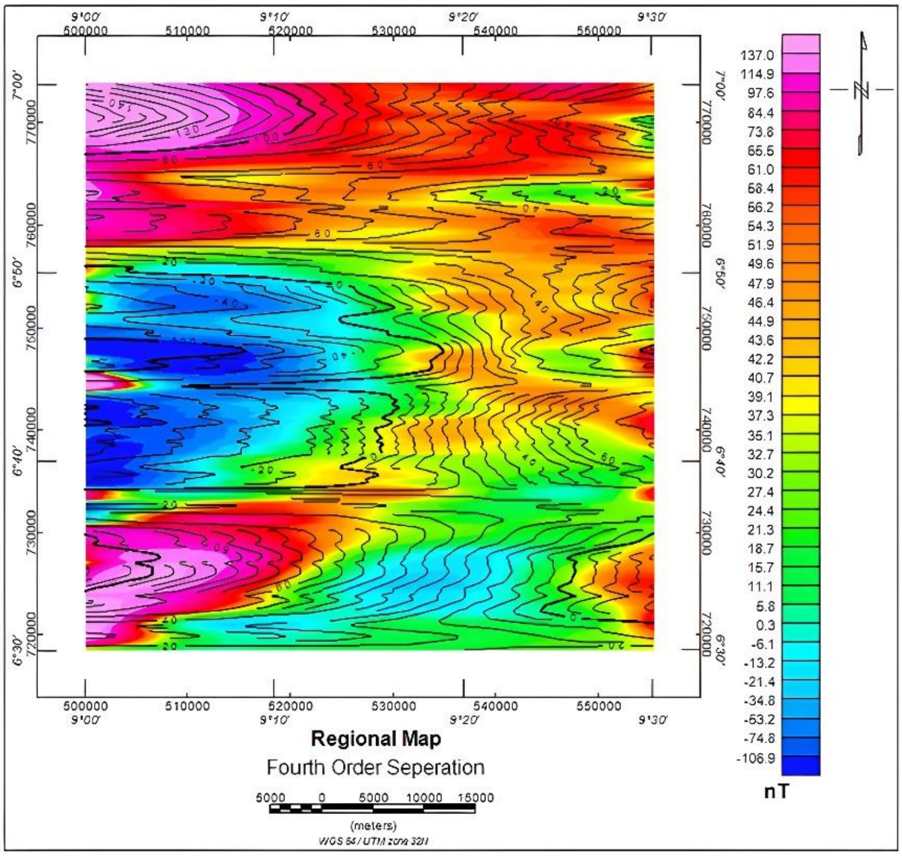

Fig. 8. Fourth Order Regional Map of the Study area.

Residual Anomaly Maps

As depicted in Figures 9, 10, 11, and 12, the residual anomaly maps of the first to fourth order were generated by subtracting the measured magnetic field from the regional maps of the polynomial surfaces. The residual anomaly maps demonstrate varying amplitudes that align in a northeast-southwest and northwest-southeast direction, similar to the studied region's total magnetic intensity (TMI) map. The anomalies seen in the research location can be attributed to variations in the magnetic susceptibilities of the underlying sedimentary and igneous rocks. The presence of subsurface heterogeneities within the upper crust is responsible for the observed variations in magnetic susceptibility. The residual maps frequently exhibited positive and negative anomalies, which served as evidence of variations in the wavelengths and frequencies of the causative sources. The maps illustrate the interrelationship between the research region's deep-seated and near-surface geological properties. The irregular subsurface topography depicted by the contrasting magnetic signals on the maps can be attributed to basement uplifts, magmatic intrusions, or basement subsidence (Cratchley, 1985; Schull et al., 1988; Schuster et al., 2005; Schuster et al., 2003). The residual anomalies seen in the region are accompanied by a pronounced gradient that exhibits a downward inclination. This gradient potentially indicates a correlation with structural geological boundaries.

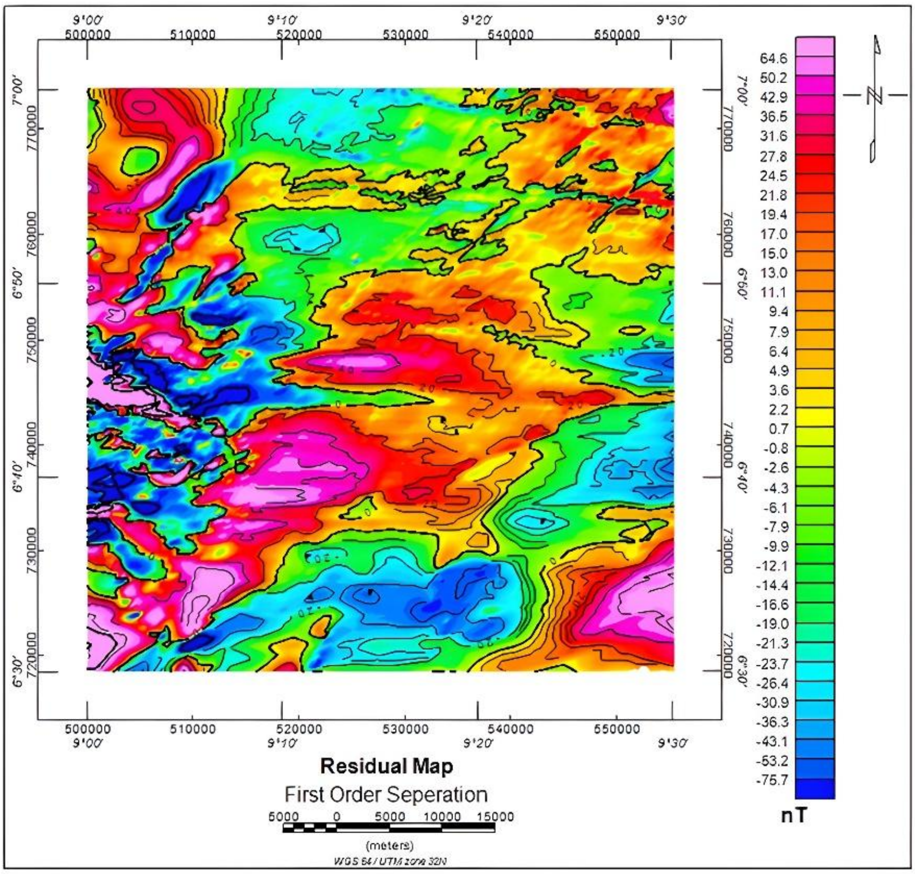

Fig. 9. First Order Residual Map of the Study area.

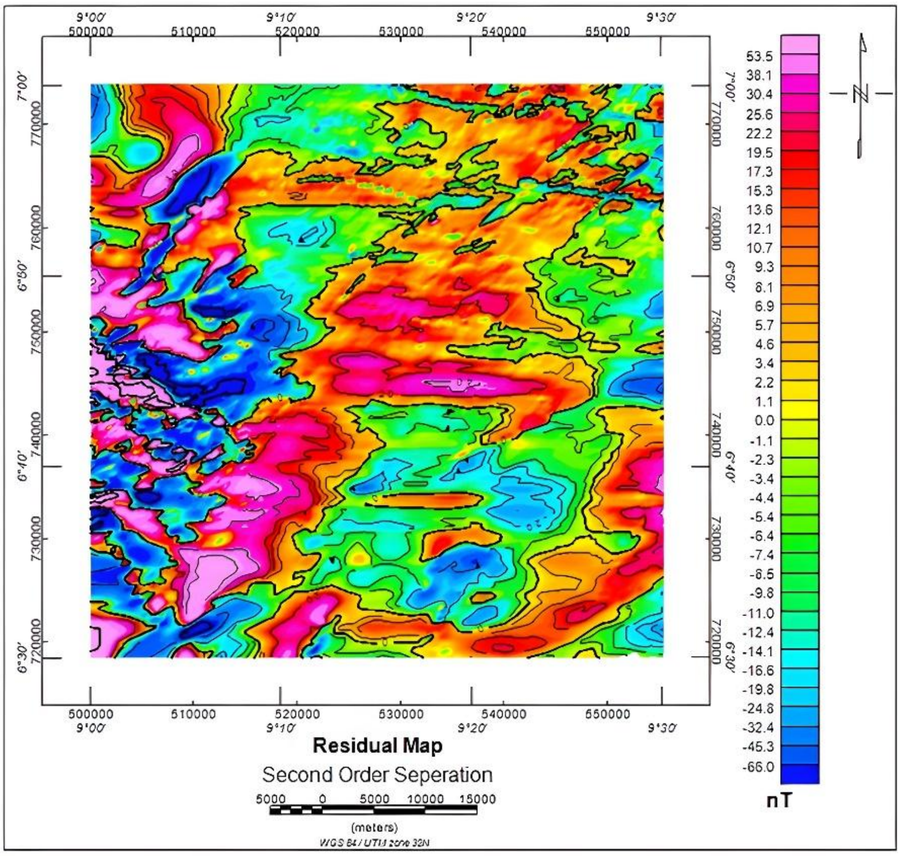

Fig. 10: Second Order Residual Map of the Study area.

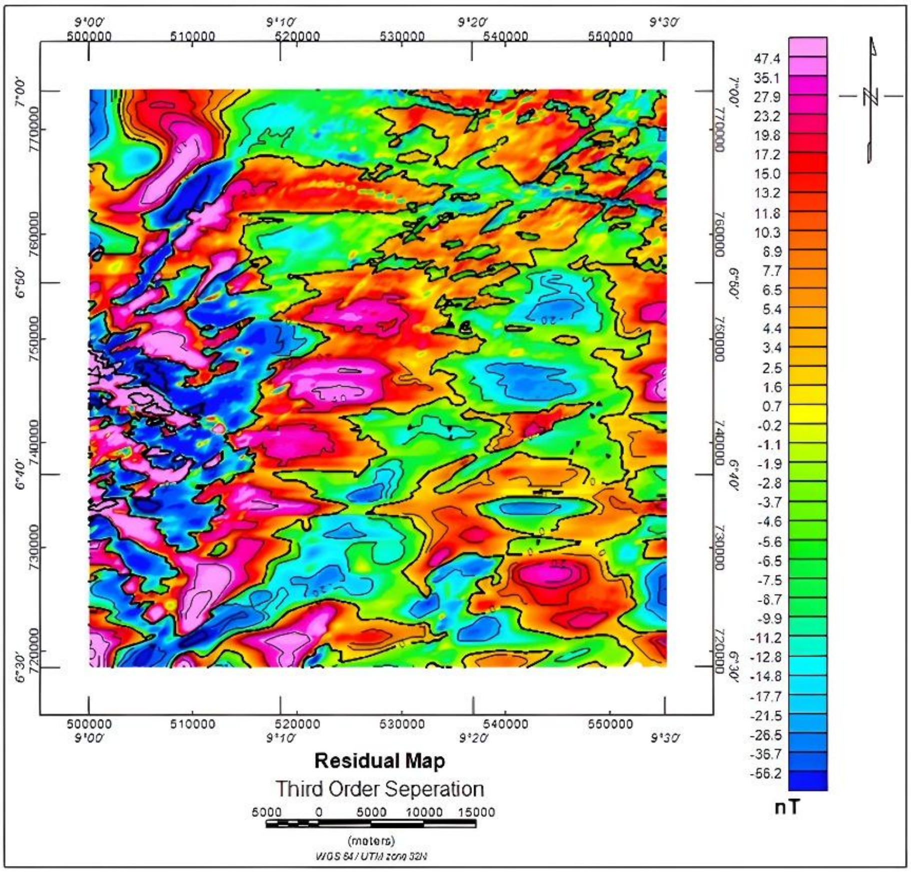

Fig. 11: Third Order Residual Map of the Study area.

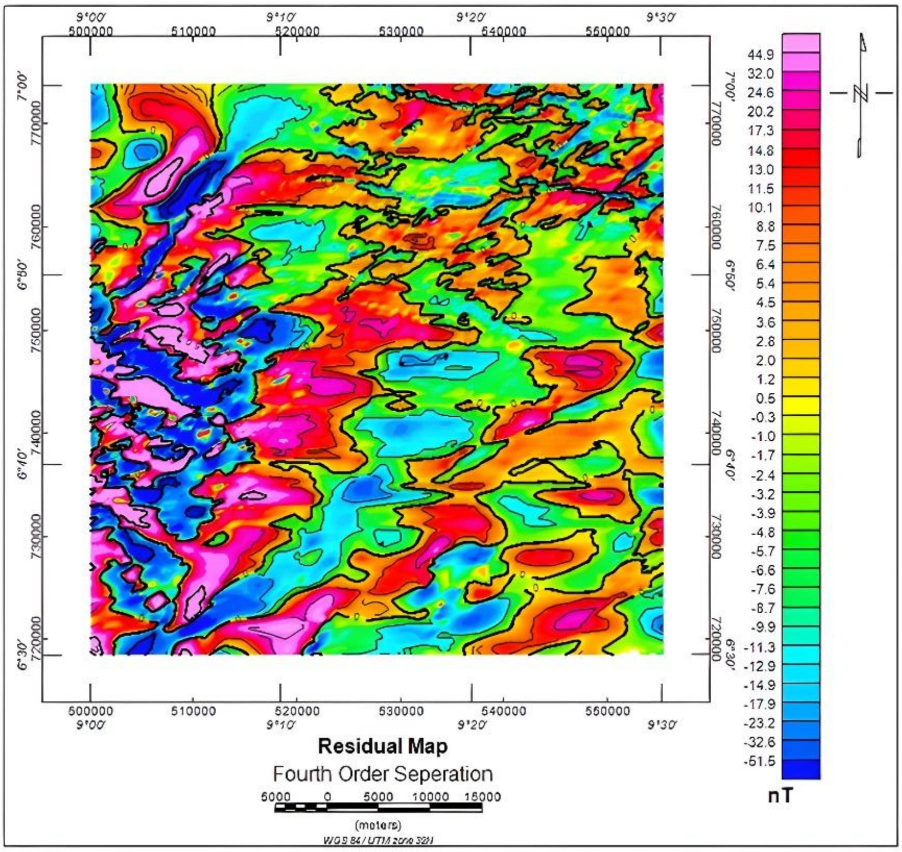

Fig. 12: Fourth Order Residual Map of the Study area.

Lineament Interpretation

The structural geometry of the research region was determined through the integration of findings obtained by applying edge enhancement filters to the aeromagnetic data, which facilitated the mapping of linear geological features. The lineaments seen in the geological formations have been analyzed and interpreted as evidence of tectonic events that influenced their development. The linear anomalies exhibit significant trends mostly in the northeast-southwest and northwest-southeast directions while displaying minor trends in the east-west direction. The presence of these factors often influenced the distribution of mineralization zones in the research region.

Horizontal Derivative Map

The horizontal derivative (HD) is an essential filter for enhancing edges, which can be employed to detect faults, fractures, joints, and other linear geological structures hosting hydrothermally changed minerals in basement complex terrains. Figure 13 depicts the horizontal derivative map, which showcases the spatial distribution of connections within the research region. These contacts primarily pertain to linear geological features that are in proximity to the Earth's surface. The map exhibits significant anomalies that suggest a directional movement in the northeast-southwest and northwest-southeast orientations. The HD map has elevated lineament densities in its northeastern and western parts. The observed phenomenon can be attributed to the upward movement of the Earth's crust in the northeastern part of the studied area due to the intrusion of magma, followed by a subsequent downward movement in the western sector of the research region.

The maximum horizontal displacement (HD) can be comprehended by establishing a connection between it and the fault structure or the boundary of lineaments in crystalline basement rocks (Setyawan et al., 2015). This work has established that the HD anomaly map of peaks corresponds to lineaments of crystalline basement rock, while its minimum values correspond to basement depressions where sedimentary materials have been collected. The primary divisions within the study region are characterized by major lineaments that traverse the area in both the northeast-southwest and northwest-southeast orientations.

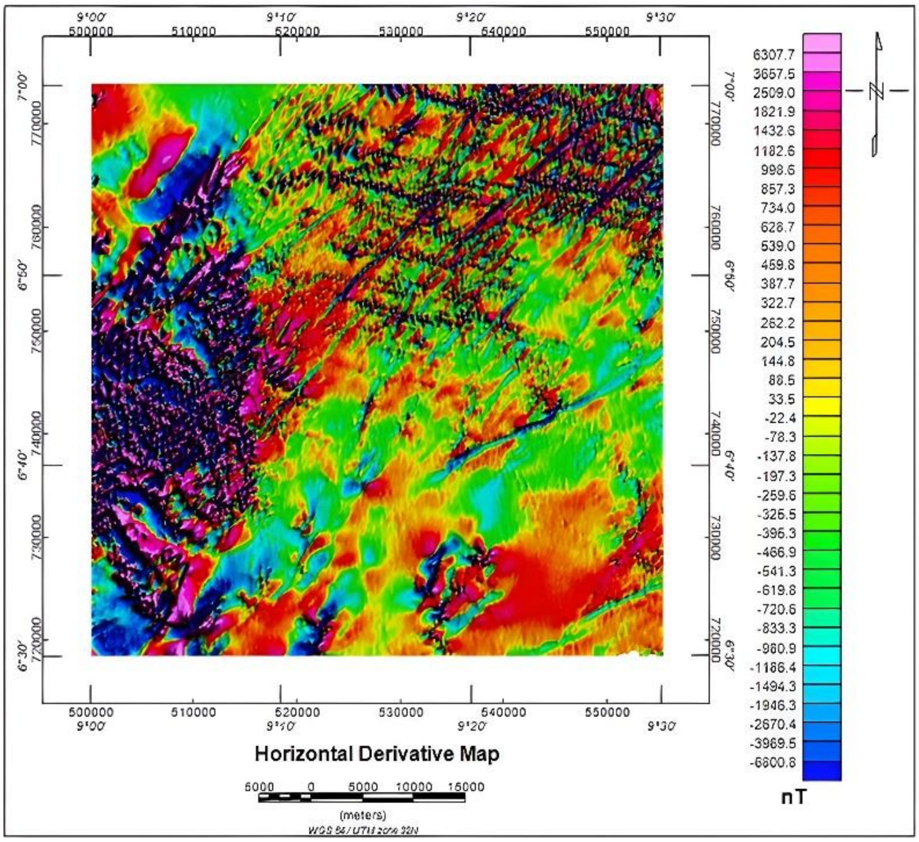

Fig. 13. Horizontal Derivative Map of the Study area.

Vertical Derivatives

The vertical derivatives enhance the sharpness of the edges of high-frequency anomalies close to the surface or shallowly seated geological features. The derivative filter enhances the clarity of lineament boundaries and contacts in comparison to the original total magnetic intensity map by selectively amplifying shorter wavelength influences while attenuating wider or regional impacts. Hence, places characterized by substantial regional instability facilitate the identification of smaller anomalies. Therefore, in order to enhance the clarity of high-frequency characteristics that may be overshadowed by low-frequency anomalies with significant amplitudes, the utilization of the First Vertical Derivative (FVD) is implemented to delineate these attributes more accurately. According to Reeve et al. (1997), it is asserted that in the context of an aerial magnetic investigation, the computation of the first vertical derivative is tantamount to the direct measurement of the vertical gradient by the use of a magnetic gradiometer. This strategy offers the advantage of enhancing near-surface magnetic sources and enhancing source resolution similarly. In order to enhance the magnitude of this effect, it is possible to compute second, third, and subsequent vertical derivatives. Nevertheless, beyond the second vertical derivative, the signal in the dataset becomes more discernible compared to the background noise (Reeve et al., 1997).

The figures depicting the maps of the first and second vertical derivative filters, namely Figures 14 and 15, showcase the enhanced lineaments observed inside the research region. The study area has prominent linear geological features at the surface, primarily oriented in the NE-SW and NW-SE directions, as seen from a visual examination of the maps. The maps provide an enhanced understanding of the structural patterns within the Obudu region, as well as the location and direction of identified geological features. Furthermore, the utilization of aeromagnetic data in the analysis of structural patterns in the basement and sedimentary terrains is effectively demonstrated by the high-resolution depiction of lineaments within the study area through the First Vertical Derivative (FVD) and Second Vertical Derivative (SVD) maps. Therefore, the maps exhibited the precision with which the filters successfully delineated the boundaries of shallow-seated geological characteristics that could serve as the sites for hydrothermally altered mineralization zones, along with the mechanisms governing the confinement in the examined area.

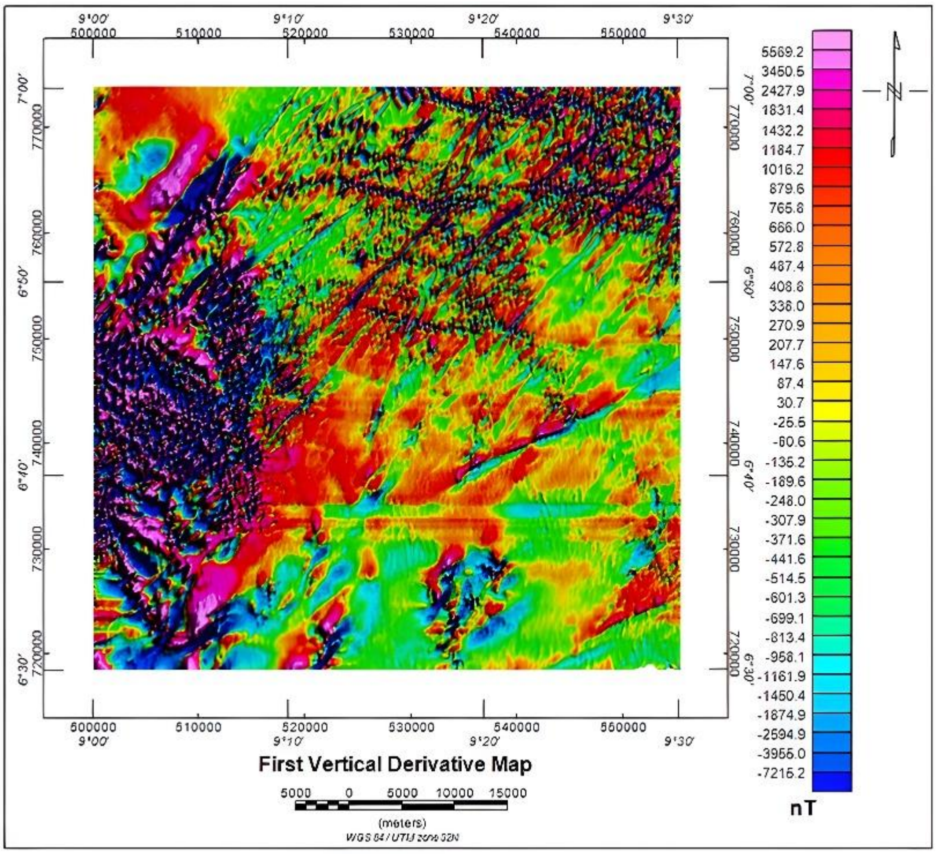

Fig. 14. First Vertical Derivative Map of the Study area.

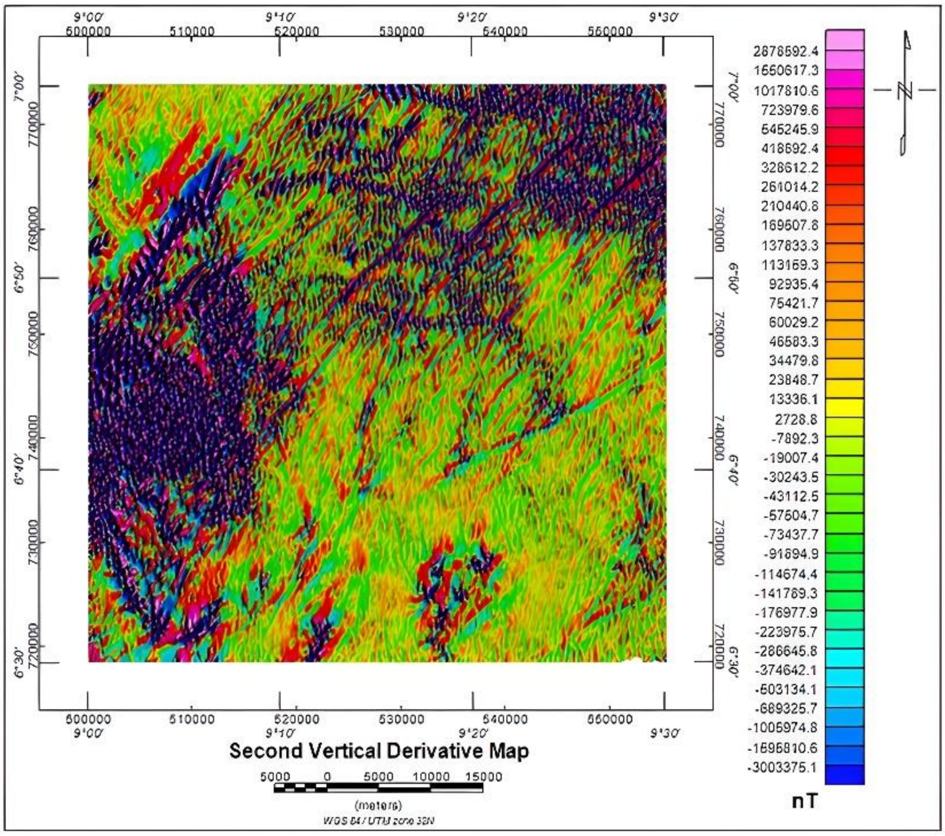

Fig. 15. Second Vertical Derivative Map of the Study Area

Depth to Basement Analysis

The widely employed Euler deconvolution technique was utilized to ascertain the spatial separation of magnetic sources. Within the examined geographical area, the Euler solutions exhibited variations in the vertical extent of many anomalous causal features. In order to identify solutions for geologic models involving contacts/faults with vertical offset and dykes, structural indexes of 0, 1, 2, and 3 were utilized (see Figures 16, 17, 18, and 19). The standard Euler method successfully detected magnetic sources located at depths ranging from 0 to 2 km. The complete resolution of depth solutions associated with deeper magnetic sources was hindered by the potential masking effects of local magnetic sources. The maps displayed the depths of the primary magnetic entities beneath the research area. The depth estimations provided are representative of the sedimentary thickness seen in the study area since they align with the commonly observed depth to the basement.

One of the primary benefits associated with Euler deconvolution techniques is its utilization of a depth weighting methodology, which enables the identification of the arrangement and structure of basement rocks and the determination of the depth to basement rocks at different solution sites. The determination of the thickness of the overlying sediments plays a significant role in estimating the depth of the magnetic sources in the research location. This was achieved by the implementation of a depth weighting study.

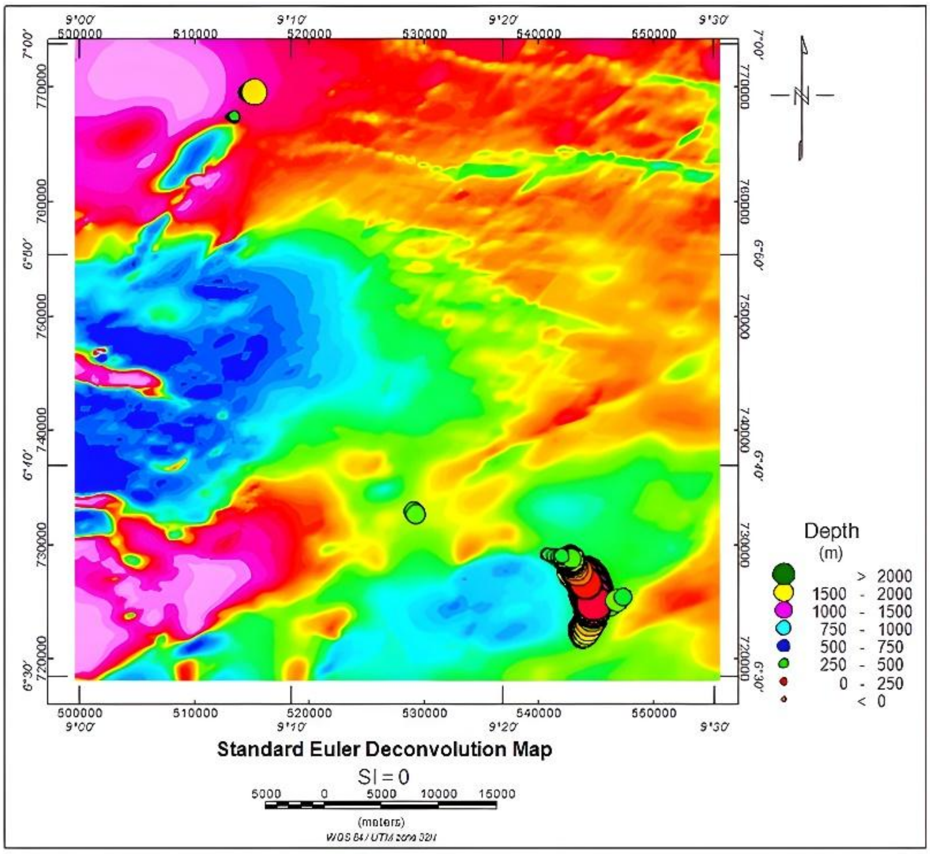

Fig. 16. Euler depth solution plot of the study area (Structural Index 0.0).

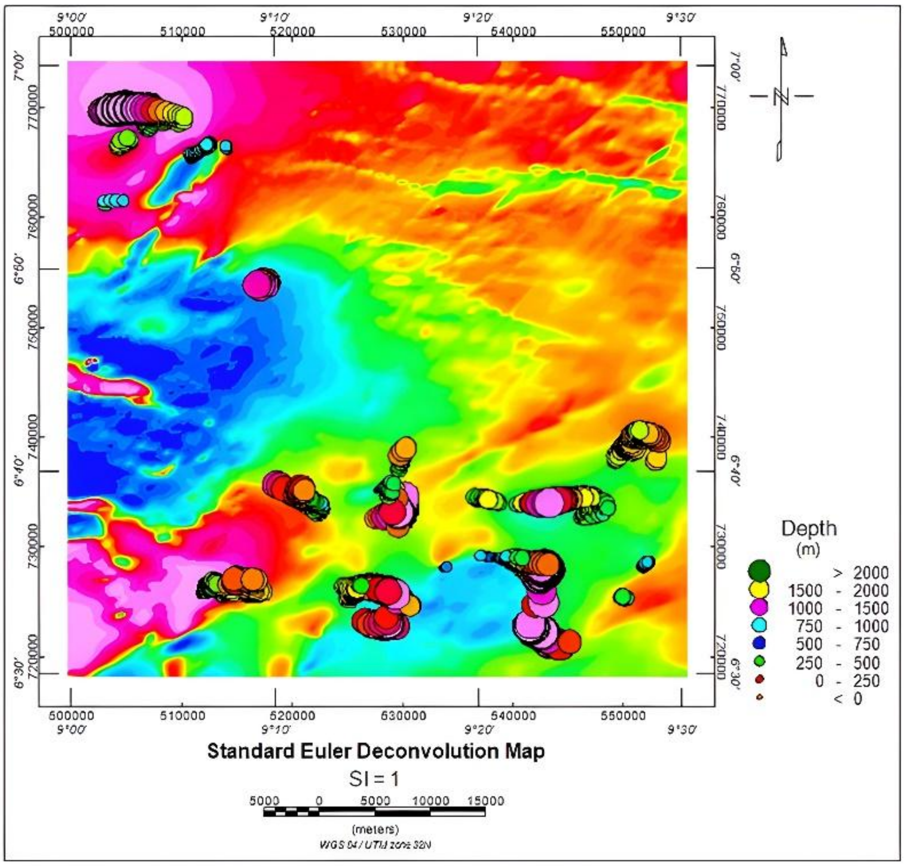

Fig. 17. Euler depth solution plot of the study area (Structural Index 1.0).

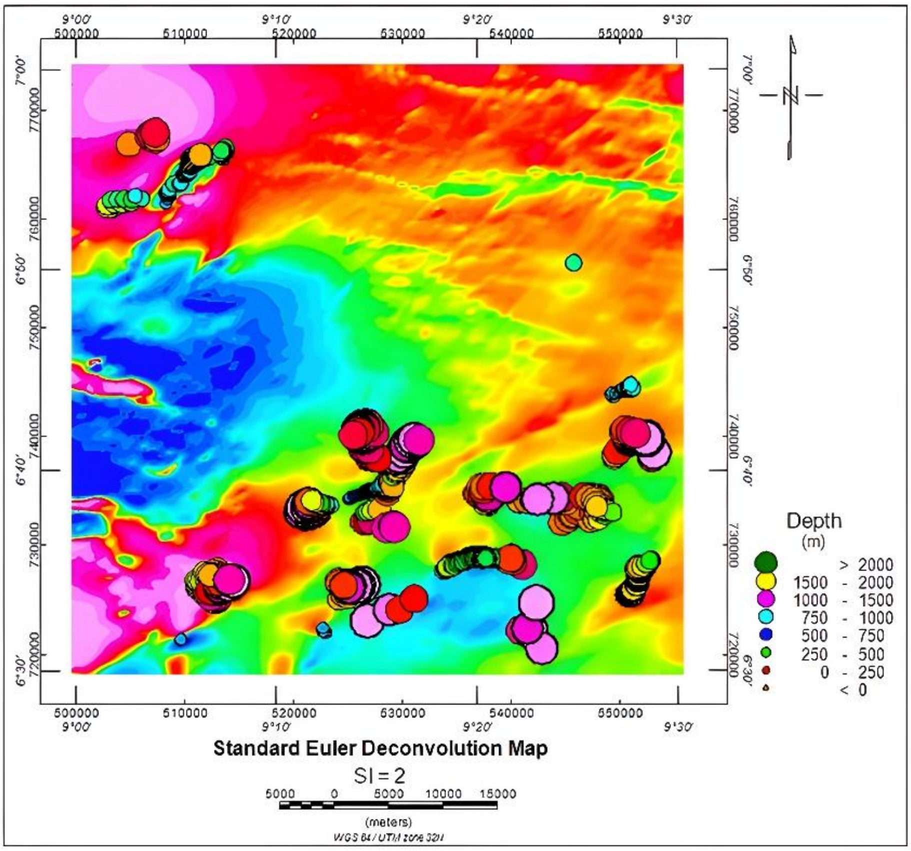

Fig. 18. Euler depth solution plot of the study area (Structural Index 2.0).

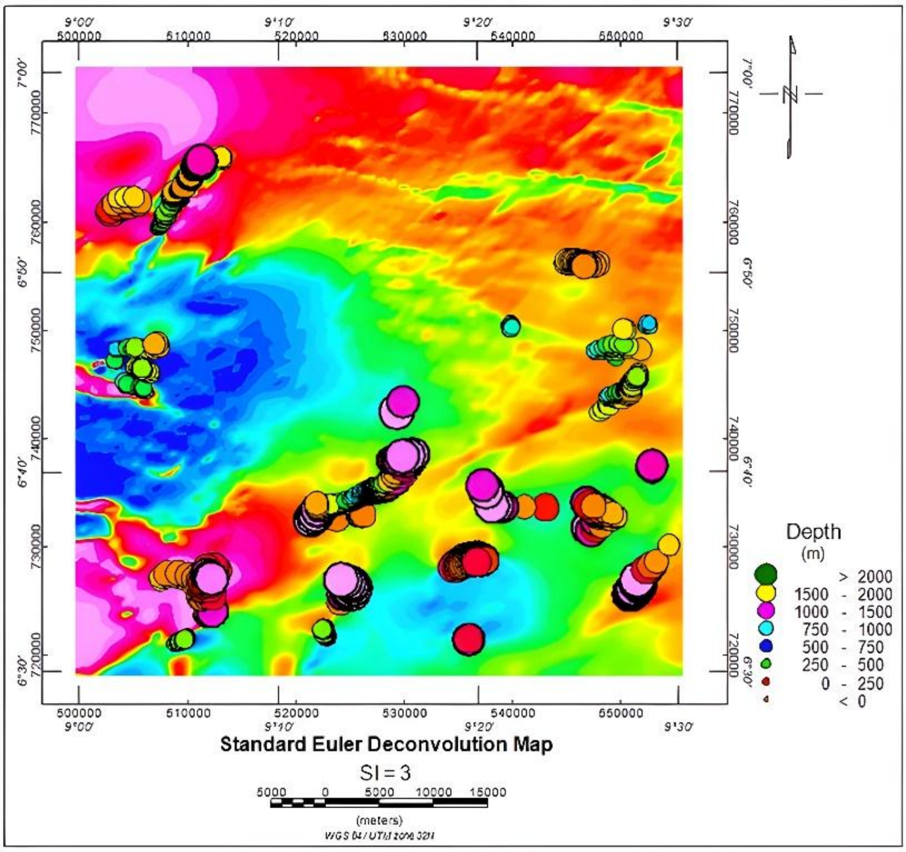

Fig. 19. Euler depth solution plot of the study area (Structural Index 3.0).

Conclusion

This study presents a geophysical analysis of high-resolution aeromagnetic data collected over the Obudu region in southeast Nigeria. The results reveal distinct areas that exhibit potential for magnetic ore exploitation, as evident in the Euler maps depicted in figures 16 to 19. Figure 19 particularly highlights the presence of magnetic ore deposits, represented as clusters characterized by spherical, cylindrical, and cone shapes. It is recommended that drilling activities be conducted in these specific places to exploit the ore resources inside them. The magnetic anomalies observed in the TMI data were found to correspond to the variations in magnetic susceptibilities of the underlying sedimentary and basement rocks in the investigation area. The aeromagnetic data was processed using a polynomial fitting approach to derive regional and residual maps. These maps revealed variations in the anomaly amplitudes, exhibiting distinct patterns in the northeast-southwest, northwest-southeast, and east-west orientations. The structural enhancement filters, namely the horizontal derivative, first vertical derivative, and second vertical derivative, were utilized to identify linear characteristics in the best-fit residual. These characteristics had a strong link with the geological features of the research area. Moreover, the limits of the shallow-seated geologic structures in the research region were accurately identified using the HD, FVD, and SVD filters. The maps exhibited distinct structural trends oriented along the NE-SW and NW-SE directions. Typically, the predominant geological formations had an NE-SW trend, aligning with the structural orientation of the Benue Trough. The depths of the lineaments and magnetic ores depicted in Figure 19 were calculated using the traditional Euler deconvolution method, which is applicable for structural indices ranging from 0 to 3. The shallow-seated geologic structures have been shown to have frequent associations with base metal, brine, and metallogenic mineralization. This relationship has been observed within a maximum depth of 2km, as indicated by the Euler solution maps.

In this work, it is seen that mineralization and short wavelength anomalies are commonly associated with areas characterized by complicated geological features (Ekwok et al., 2019). The application of FVD and SVD high-frequency filtering techniques demonstrated that the study area exhibits significant amplitude anomalies, which can be attributed to the presence of basement rocks with a high density and a substantial concentration of magnetite, as previously mentioned by (Ekwok et al., 2019). The horizontal derivative analysis accurately determined the source body's position, boundary, and orientation inside the studied area. The visual representation consists of a linear arrangement of symbols, depicting the interactions between different rock units and the geometric features of the entities responsible for these interactions. Prominent features observed in the Obudu region were identified on the FVD (Frequency Vector Diagram) and SVD (Singular Value

Decomposition) maps. The predominant structural pattern observed is the alignment of lineaments in a northeast-southwest direction, corresponding to the Benue Trough's orientation. According to Agbi and Ekwueme (2018), the geological features seen in the study area were a result of tectonic events. These events caused the formation of the mentioned geologic characteristics (Woakes et al., 987) as well as the intrusion of Quaternary-Recent basaltic materials into the Cretaceous and Precambrian strata of the Obudu Plateau (Ekwok et al., 2019). The Obudu region exhibits a high concentration of short wavelength anomalies. The classification of this region is based on its hydrothermal and geothermal alteration, which can be attributed to the existence of faults, fractures, fissures, dykes, sills, baked Albian shales, and other potential radiometric ores. These geological features contribute to the region's suitability as a potential site for geothermal energy exploration (Oha et al., 2016; Ekwok et al., 2019). The observed abnormalities are associated with the predominant tectonic structures present in the area. Hydrothermal fluids exhibit movement and deposition within the channels of these geological structures.

The aerial magnetic data was utilized to generate enhanced structural maps by applying HD, FVD, and SVD filters. These filters successfully delineated the borders of the shallow-seated geologic formations that have the potential to host hydrothermal and geothermal minerals. The regional and residual anomaly maps obtained in the research area unveiled the geologic distributions and variations in magnetic susceptibility of the underlying sedimentary and basement rocks. The spatial properties of the created geologic features, including their position, orientation, number, and subdivision, were all depicted on the anomaly maps. The evaluation of the structural map revealed significant structural patterns oriented in the northeast-southwest and northwest-southeast directions. The structural map generated by the FVD and SVD analysis revealed a highly consistent and prevalent pattern. The results gained provided evidence for the use of magnetic data as a reconnaissance tool in the identification of hydrothermal mineral alteration zones. This was achieved by correlating the geological structures derived from the magnetic data and the adjacent mineralization zones.

The findings of this study demonstrate that the generated maps or solutions serve as valuable tools for visualizing lineaments in a complex geological area. Additionally, when combined with surface geologic structural mapping, these maps can effectively identify regions that may contain significant magnetic ore deposits, particularly in areas characterized by multiple periods of deformation. The congruence between the Precambrian basement regions' locations, as depicted in the high-frequency TMI maps, and the geologic distribution of the primary short wavelength anomalies is notable. The provided maps serve to elucidate the primary magnetic zones and contribute substantially to our comprehension of the spatial arrangement of short-wavelength anomalies in the Obudu region. The findings strongly align with prior findings in the region, as indicated by Oha et al. (2016). The validity of the positions and depths of magnetic ores and lineaments is further substantiated by the traditional Euler deconvolution maps. The maximum depth of 2km seen in the Euler solutions further highlights the relatively shallow depths of the lineaments, underscoring their importance in the conte;xt of mineral extraction.

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