Indonesian Journal of Earth Sciences, Vol. 04, No. 2 (2024), A1265

P-ISSN: 2798-1134 | E-ISSN: 2797-3549 | DOI: 10.52562/injoes.2024.1265

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Indonesian Journal of Earth Sciences

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Delineating Structural Features Related to Hydrothermal Alterations for Possible Mineralization in Share Area, Kwara State Nigeria Using Aeromagnetic Data

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Received: 23 July 2024 / Accepted: 25 December 2024 / Published: 27 December 2024

Abstract: Mineral deposits of significant economic value are abundant in the subsurface of Nigeria, presenting a promising alternative to the nations over dependence on petroleum revenues. This study interprets aeromagnetic data from Share, Kwara State, Nigeria, to delineate subsurface structural features associated with hydrothermal zones, which are key indicators for potential mineralization. The methodologies applied upward continuation, analytic signal, tilt derivative, and first vertical derivative (FVD). These offer insights into subsurface geology that can be broadly applied in geophysical exploration and mineral resource management. The results reveal structural trends predominantly in the NE–SW direction, with some NW–SE alignments, indicative of hydrothermal alterations linked to mineral deposits. The analytical signal map identified amplitude values ranging from 0.004 nT/m to 0.073 nT/m, with low and intermediate magnetic intensities linked to sediment-filled basement rocks and possible limestone and sandstone formations. High-gradient anomalies, 1.280 nT/m to 1.374 nT/m, were attributed to geological contacts, fractures, dykes, and hydrothermal vents. Depth estimates from the source parameter imaging map revealed hydrothermal and structural zones at depths ranging from 287.9 m to 1360.7 m, with deeper sources >1202.1 m indicating tectonic activity and mineralization potential. The FVD and Tilt Derivative maps further highlighted faulted zones, shear structures, and intrusive bodies with intensities between 0.031 nT/m and 0.041 nT/m, suggesting active tectonics. High magnetic anomalies in the central, northeastern, and southeastern regions were identified as prime targets for exploration, indicating magnetite-rich bodies, igneous intrusions, and hydrothermal zones. Integrated exploration strategies combining geophysical, geochemical, and structural data are recommended to refine anomaly delineation, prioritize field validation, and enhance mineralization discovery. These findings establish the Share area as a promising site for regional mineral exploration, supporting Nigeria's diversification efforts toward sustainable resource development.

Keywords: Hydrothermal Alteration, Enhancement techniques, Upward continuation, Analytic signal, Tilt derivative, Hydrothermal Vents, Tectonic activity

INTRODUCTION

The global shift towards sustainable and diversified economies has amplified the need for alternative resources to reduce dependence on petroleum, particularly in regions like Nigeria, where economic stability has long been tied to hydrocarbon revenues. Mineral resources offer a viable substitute, providing opportunities for economic diversification and growth. Identifying and harnessing these resources necessitates a robust understanding of subsurface geology and the structural features that control mineralization. This is especially true in areas with complex geological histories, such as the Share area in Kwara State, Nigeria. Nigeria's heavy reliance on petroleum revenues has exposed its economy to the volatility of global oil prices. This instability has caused budget shortfalls and increased borrowing to finance critical infrastructure and development projects. On the other hand, Nigeria is endowed with a basement complex terrain that serves as a host of several metallic and nonmetallic mineral resources. Many mineral deposits of great economic importance (Figure 1) have been discovered in abundance throughout the country's subsurface (Olade, 2019), although a good number of the mineral resources remain untapped. Their occurrence, content, and volume of reserve have not been fully examined in certain other places. This study aims to use aeromagnetic data to map Share, Kwara state, sheet 202, to delineate the structural features/systems of the subsurface related to hydrothermally altered zones which can serve as host to excellent mineralization zones, to find a close substitute to petroleum source of income/revenue for the government of the country. Unlike earlier studies that relied primarily on individual geophysical methods, this study employs a combination of upward continuation, analytic signal, tilt derivative, and first vertical derivative methods. This integrated approach enhances the precision of subsurface imaging and allows for a comprehensive analysis of both shallow and deep structural features.

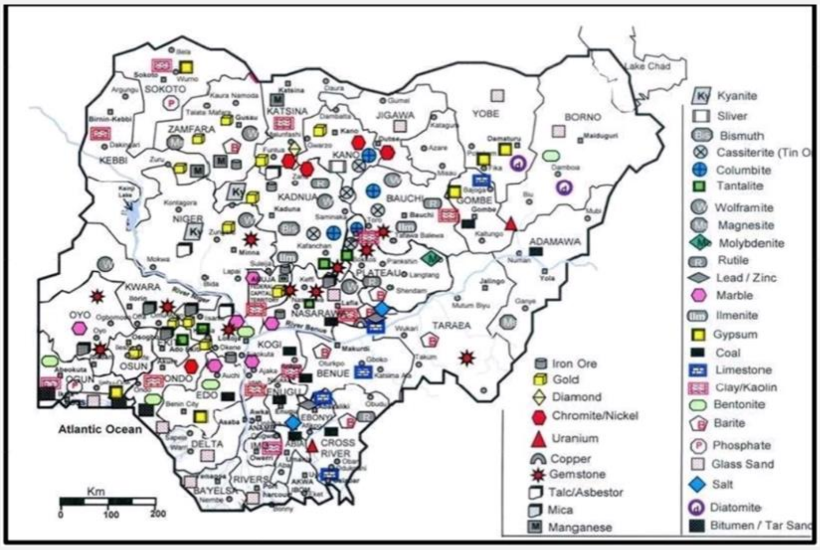

Figure 1. Map showing mineral occurrence in Nigeria (Olade, 2019).

A hydrothermal alteration zone is a geological process that provides valuable information on the type and the location of mineral elements present in a particular expanse of land. This zone can be formed when hot fluids derived from magma (molten rock) or heated groundwater interact with rocks near the surface (Robb, 2020; Rushmer, 1991). The hydrothermal solution rises through the cracks and fractures and picks up dissolved minerals and elements on its path, as a result altering the original rock. Mapping hydrothermally altered rocks is integral to reconnaissance mineral exploration (Andongma et al., 2021). The mapping can thus be accomplished with the help of aeromagnetic measurement due to its capability to map local intrusions and structures (Eldosouky et al., 2017).

In Nigeria, Kwara is one of the states that play host to solid minerals in commercial quantity. This was confirmed by the aeromagnetic survey conducted by the Nigerian Geological Survey Agency. The minerals are believed to align along the geological structures such as faults/fractures present in the area owing to events such as hydrothermal alteration. This study seeks to investigate in detail the new locations related to hydrothermal alteration as regards mineralization in the study area.

The magnetic method is a geophysical exploration technique that is widely acceptable as the most efficient method to study the subsurface properties of the planet (earth) based on fluctuations that occur in its magnetic field (Mohamed & Al Deep, 2021; Saleh et al., 2018). It relies on the fact that rocks and minerals in the Earth's crust possess different magnetic properties, and these variations can be detected and analyzed to infer geological structures, mineral deposits, and other subsurface features (Abuelnaga et al., 2020). The aeromagnetic data acquisition requires mounting a magnetometer on an aircraft which will be flown over a study area in a predetermined grid pattern to acquire the magnetic variation data of the subsurface.

There exists no direct relationship between mineralization and magnetic anomalies unless the host rocks contain minerals that give magnetic anomalies measurable at the surface. Also, by induction Ter Maat et al. (2019) opined that low-intensity anomaly could be associated with mineralization of low magnetic responses. Kwara state predominantly has mineralization associated with Hematite, Pegmatite (of Gold, Lithium etc. associate), and Granite Gneiss which are of high magnetic intensity. There is also the presence of low magnetic intensity mineralized rocks such as Quartzite, and Schist (of marble associate), to mention a few. Thus, magnetic high and low responses could serve as identifiers of any of those available minerals in the area.

Share area of Kwara state Nigeria has received many exploration techniques of geophysical studies confirming the occurrence of mineralization within the area. Deduction from the research of Megwara & Udensi (2014) showed that mineralization is controlled structurally with kaolin occurring along lineaments in the Share area. Olawuyi & Bawallah (2022) carried out an integrated magnetic, self-potential (SP) and electrical resistivity survey with the main goal of delineating the subsurface layers in the transition environment between the Nupe basin and the Nigerian Basement Complex at Ikanje-Share in Kwara state, Nigeria. The study determined the geological characteristics and also identified geological structures like faults and fractures that could be responsible for perennial spring formation. More recently, possible structural features have also been delineated in a part of North-central Nigeria by Lawal et al. (2024) using high-resolution aeromagnetic and aeroradiometric datasets. The results of their study showed that the area is dominated by structures that favour the occurrence of mineralization within the area. However, this study seeks to investigate probable new locations of fault zones and estimate the magnetic source depth, and their evolution in controlling the mineralization of economic mineral deposits for development.

Study Area and Geology

The study area includes a local settlement under the Ifelodun council of Kwara state, Nigeria. The area has a latitude of 8030' 00"N to 90 0' 00" N, a longitude of 4030' 00" E to 500' 00" E and a surface area of approximately 3080.25 km^2. The study area with nuclear settlement is situated at a distance of about 80 km northeast (NE) of Ilorin, the capital of Kwara state. The area has an uneven (undulating) topography. The elevation ranges from about 1150 m (highest) to about 650 m (lowest). Rocky outcrops are common within the elevated areas. The drainage system appears like branches of root (dendritic).

The Geology of Kwara state is dominated by three major rock types; Basement Complex, Schist belt, and Sedimentary Basins (Obaje, 2009). Geologically, the Share area located in Kwara State, Nigeria lies within the southwest portion, and the underlying rock is the basement complex rocks of Northern Nigeria (schist belt) (Figure 2). The area is thought to include lithologies and other suitable circumstances for hydrothermal changes and mineralization (Olawuyi & Bawallah, 2022). The basement complex rocks within the Share area are Ediacaran in age and are also covered in some part by Basin and rift-filling sediment of cretaceous to recent age (Tijani, 2023).

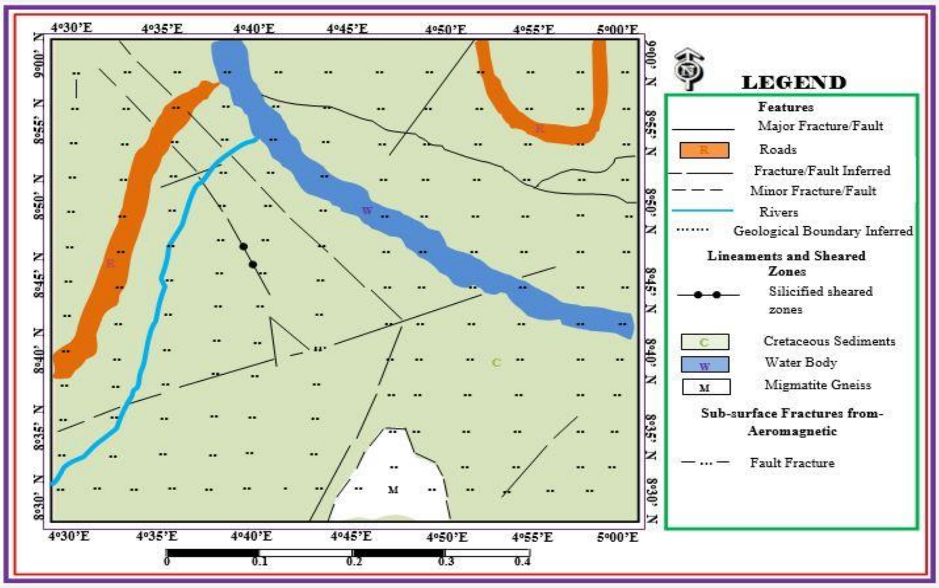

Figure 2. Geologic map of Share.

The Share area in Kwara State, Nigeria, is underlain by the Basement Complex rocks of Northern Nigeria, specifically the Schist Belt, which is known for its diverse lithologies and mineralization potential. This region is part of the southwestern Nigerian Basement Complex, which forms a portion of the Pan-African orogeny and consists of older granites, schists, migmatites, and gneisses, interspersed with intrusive igneous rocks. These lithologies provide favorable conditions for hydrothermal alterations that can lead to mineralization. Recent studies indicate that the granitic rocks, covering approximately 65% of the Share area, are predominantly biotite granites and granodiorites, which are often associated with metallic mineralization, including gold and rare earth elements (Adebayo & Obasaju, 2021). Additionally, the schistose rocks in the area, including quartz-mica schists and amphibolites, serve as hosts for metamorphosed hydrothermal systems that further enhance the potential for mineral deposits. Lithologic variations in the Share area include zones of pegmatitic intrusions that are notable for hosting lithium-bearing minerals and gemstones such as tourmaline. These pegmatites are aligned along major fault zones, which act as conduits for mineralizing fluids (Olawuyi & Bawallah, 2022). The presence of quartzite and marble within the schist belt further supports the area's capacity for hosting economic mineral deposits, including those formed through contact metamorphism and hydrothermal processes. The region's tectonic setting is characterized by NE–SW and NW–SE trending faults and fractures, which are products of the Pan-African orogeny. These structures have been reactivated over geological time and are critical for the emplacement of mineral-rich hydrothermal fluids (Abraham et al., 2024). The tectonic framework not only controls the distribution of lithologic units but also influences the localization of mineralization zones.

MATERIAL & METHODS

The data set (total intensity magnetic data) was acquired from an agency of the federal government of Nigeria, NGSA, Abuja. The secondary data acquisition which started in year 2005 and ended in year 2010 was carried out by Fugro airborne services over the entire Nigeria land area. The Cesium Vapour magnetometer was mounted on an aircraft, taking recordings at intervals (approximately 0.1 s), at an elevation and line spacing of 80 m and 500 m respectively. The other important specifications of the survey include a corresponding flight line direction and tie line trend of 1350 and 450. The survey data were thereafter published as half-degree-by-half-degree (500 m by 500 m) maps of total magnetic intensity on a scale of 1 to 100000 (Sanusi & Amigun, 2020). Figure 3 is a flowchart for the geophysical data processing steps.

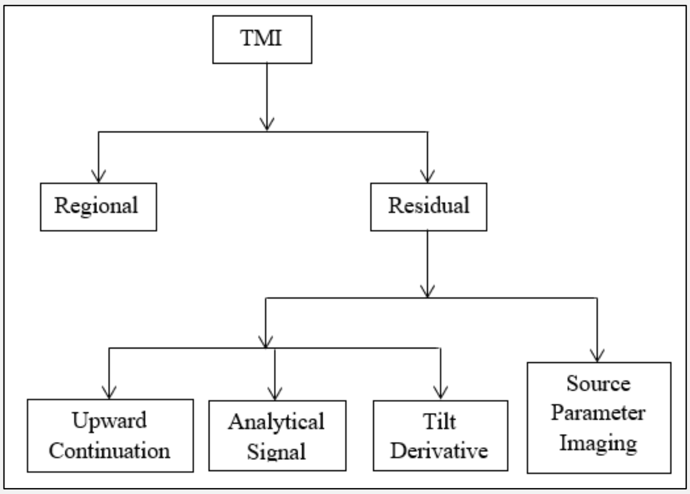

Figure 3. Flowchart for the aeromagnetic data processing steps.

Partition into a regional-residual field is a basic step necessary ahead of interpreting the magnetic variance data of a particular area. It is defined as the determination of predicted residual fields by taking the estimated regional field values away from the observed total magnetic field values (Gabtni & Jallouli, 2017). The partitioning of the regional-residual fields of the TMI data in this work aids in emphasizing/separating long wavelength (regional) from the high frequency (residual) content, which is important in mineral prospecting. As a result, the residual magnetic intensity primarily plays a crucial role in understanding the subsurface, identifying potential hydrothermal zones, and mineral resources and also monitoring geological activities of the study area.

The aeromagnetic data was further processed using Geosoft Oasis Montaj 6.4.2 software. In an attempt to filter high-frequency noise that originates from sources closer to the ground surface and thereafter strengthen the deep-seated rock formations, upward continuation was first performed. The rationale for choosing upward continuation is based on the need to focus on magnetic anomalies that are associated with deeper sources, which are more relevant for understanding the subsurface geology, especially in mineral exploration and structural analysis. However, it should be used with caution, especially in areas with complex geology or where shallow features are of interest, as it can smooth out important details (Balogun et al., 2023). The maximum elevation within the study area, according to Olatunji & Abubakar (2024), is 366 m above sea level. Consequently, upward continuation was performed to a plain level of 500 m, which is higher than the highest means sea level in the area. Although the total horizontal gradient filter is highly recommended for edge detection, the method is sensitive to noise, prone to smoothing and has difficulties in detecting weak edges (Thanh Pham et al., 2021). The filter is also not suitable in areas with complex geology like Share, Kwara state Nigeria. Other enhancement performances used to improve the upward continued magnetic data for structural mapping are analytical signal (AnSig) (being specific in terms of horizontal and vertical derivatives of the total field), tilt derivative (being a signal discriminator for shallow and intermediate sources), source parameter imaging (ability to handle complex geology) and first vertical derivative (being effective in detecting edges and boundaries of geological structures like faults, contacts and lineament).

AnSig

The Analytical Signal (AnSig) is a geophysical technique used in processing magnetic data to map geological features, especially hydrothermal zones. Its main purpose is to highlight the edges of magnetic anomalies and identify the locations and depths of subsurface magnetic sources. This makes it especially useful in detecting boundaries between deposits and surrounding host rocks, regardless of their magnetization orientation (Abdelrady et al., 2023; Nabighian, 1972). The rationale for choosing this technique is based on its ability to provide clear insights into the location, shape, and depth of magnetic sources, even in complex geological settings (Adewumi & Salako, 2018). This technique offers several other advantages, including precise edge detection, semi-automatic depth estimation, and orientation independence, but its effectiveness diminishes when the source body's depth exceeds its size and is influenced by factors such as depth, dip angle, magnetization direction, and Earth's magnetic field (Pham & Oliveira, 2023). By enhancing the resolution of magnetic data, AnSig is instrumental in identifying hydrothermal zones, which are critical targets for mineral exploration due to their potential to host valuable deposits.

Mathematically, the analytical signal is achieved by applying Hilbert transform to the original signal. It broadly tracks the possible demarcations of deposits from their surrounding host rocks irrespective of the orientation of the body's magnetization (Keating & Sailhac, 2004; Nabighian, 1972). In three-dimensional (3D), the equation of the AnSig is given according to the formula of (Roest et al., 1992);

$$|A(x,y)| = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2} \tag{1}$$

A (x, y) is the size of the analytic signal at the (x, y) coordinate, and T is the observed magnetic variation/anomaly. $\frac{\partial T}{\partial z}$ represents the vertical derivative, $\frac{\partial T}{\partial x}$ and $\frac{\partial T}{\partial y}$ represents orthogonal derivatives (x- and y-planes) of the total field.

Equation 1 in 3D according to Li (2006), is independent of nothing but it depends/relies on numerous or every other element the magnetic field on its own depends upon. These elements include the burial deepness, extent, dipping angle of the source body, the body's magnetization direction and the Earth's magnetic field direction.

Tilt Derivative (TD)

TD is an arctangent function relating the ratio of perpendicular derivative, $\frac{\partial \mathrm{T}}{\partial \mathrm{z}}$, to those of the horizontal derivatives, $\frac{\partial \mathrm{T}}{\partial \mathrm{x}}$ and $\frac{\partial \mathrm{T}}{\partial \mathrm{y}}$, of the magnetic flux T (Miller & Singh, 1994; Salem et al., 2008; Verduzco et al., 2004). It is used mainly for image enhancement and is also capable of detecting linear trends in a specific orientation, which are often indicative of fault zones or shear structures. However, its limitations include sensitivity to noise, reduced effectiveness for deep sources, and potential challenges in highly complex or heterogeneous geologies (Ibraheem et al., 2023).

$$\mathrm{TD} = \tan^{-1}\left[\frac{\frac{\partial \mathrm{T}}{\partial \mathrm{z}}}{\sqrt{\left(\frac{\partial \mathrm{T}}{\partial \mathrm{x}}\right)^2 + \left(\frac{\partial \mathrm{T}}{\partial \mathrm{y}}\right)^2}}\right] \tag{2}$$

With values between $\pm 90^0$, TD acts as a geometric function of orthogonal derivatives of the magnetic field. The half-distance between $\pm 45^0$ contours give an approximate depth for perpendicular contacts. Distances acquired from the TD between zero and $+45^0$ or -45^0 contours show the depth to the top of those orthogonal contacts (Narayan et al., 2017; Oruç & Selim, 2011; Pal & Majumdar, 2015).

Source Parameter Imaging (SPI)

SPI is a method/technique centred on the expansion of complex analytic signals to calculate approximately magnetic basement; it can also be referred to as local wave number (Thurston & Smith, 1997). For a potential field T, the local wavenumber is expressed as below as reported by (Eldosouky et al., 2022):

$$\mathrm{d}\,(\mathrm{x},\mathrm{y}) = \frac{\frac{\partial^2 \mathrm{T}}{\partial \mathrm{x}\,\partial \mathrm{z}} \frac{\partial \mathrm{T}}{\partial \mathrm{x}} + \frac{\partial^2 \mathrm{T}}{\partial \mathrm{y}\,\partial \mathrm{z}} \frac{\partial \mathrm{T}}{\partial \mathrm{y}} + \frac{\partial^2 \mathrm{T}}{\partial^2 \mathrm{z}} \frac{\partial \mathrm{T}}{\partial \mathrm{x}}}{\left(\frac{\partial \mathrm{T}}{\partial \mathrm{x}}\right)^2 + \left(\frac{\partial \mathrm{T}}{\partial \mathrm{y}}\right)^2 + \left(\frac{\partial \mathrm{T}}{\partial \mathrm{z}}\right)^2} \tag{3}$$

According to Thurston & Smith (1997), the depth estimate obtained will depend on the model assumed and accurate estimates of the source parameters are only attainable when the structure is two-dimensional and aligns with the selected model, such as a sloping contact or a dipping thin sheet and it is based on the complex analytic signal. For buried geologic boundaries, the maximum of 'd' can be found independent of parameters such as magnetic variation (declination), angle of dip, magnetic inclination, strike, and any residual magnetization over isolated contact edges. The vertical height is projected from the inverse of the local wave number at the source boundary (Al-Badani & Al-Wathaf, 2018).

$$\mathrm{Depth}_{(\mathrm{x}=0)} = (d_{max})^{-1} \tag{4}$$

$\mathrm{d}_{\max}$ represent the climax value of the local number.

This method is particularly effective for buried geologic boundaries because it is independent of factors such as magnetic declination, dip angle, inclination, strike, and residual magnetization, provided the structure aligns with a two-dimensional model like sloping contact or dipping thin sheet. SPI is valuable for mapping hydrothermal zones as it helps estimate the depths of subsurface structures like fractures, fault zones, and magnetic bodies, which are often associated with hydrothermal alterations and mineralization. By identifying the depth and extent of these features, SPI contributes to a more detailed understanding of subsurface geology and supports targeted mineral exploration.

RESULTS & DISCUSSION

Total Magnetic Intensity (TMI) Map

The TMI map as shown in Figure 4 displays the magnetic intensity natural in the research area. The magnitude of the TMI value ranges from -79.9 nT to 132.9 nT. It shows a strong positive relationship with the geology of the research area. The minimum values of -79.9 nT to -3.7 nT are in blue and are mostly registered on the south side of the map, with a few in the northeastern part of the Share area, while the maximum value ranges from 49.9 nT to 132.9 nT and mostly observed in the centre, with scattered observations in the north and south region of Share area. The positive values may generally indicate faults or shear zones where magnetic minerals have been concentrated. It may also signify the presence of magnetic minerals such as magnetite of pyrrhotite, which are commonly associated with mafic or ultramafic igneous rocks, or sedimentary rocks with significant magnetic mineral content. Low magnetic intensity values on the other hand may signify zones of low magnetic susceptibility, often associated with non-magnetic rock types like certain granites, sandstones, or areas where magnetic minerals have been altered/oxidized.

The TMI map also reflects the differences/variations in magnetic intensity indicating that there are proportionate differences in the lithology and basement materials inherent in the research area. This permits the detection of magnetically important zones. Because of structural contact between sedimentary and basement complex rocks in the research area, hydrothermal solutions frequently flow through fault and fracture zones. Mineralizations prefer to occur in the presence of quiescent magnetism (Yang et al., 2020). The TMI also shows that the area consists of magnetized bodies at deeper sources/larger structures and magnetized bodies at shallower sources/smaller structures. The deeper sources variance within the area can be attributed to the core Precambrian vault while the smaller structure variance may also be attributed to the existence of magnetic bodies and indicative of bodies at shallower point. The general trending fabric is in the East-West bearing around the centre of the map and the Northeast- Southwest bearing and a few trending in the Northwest- Southeast bearing.

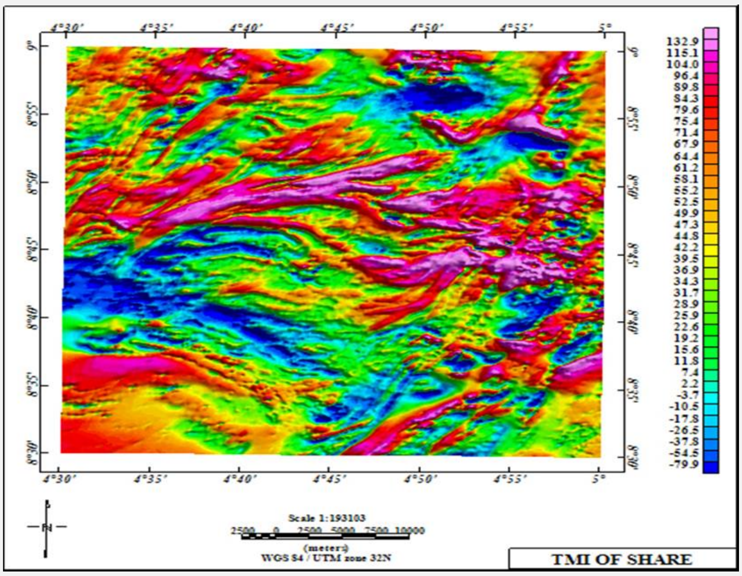

Figure 4. Total magnetic intensity map of Share.

Residual Magnetic Anomaly (RMA) Map

While the TMI shows the complete magnetic field strength including local and regional anomalies, the residual magnetic field shows the field strength after removing regional trends and noise. Figure 5 shows the residual intensity map of the Share area. The values obtained are observed to be in the range of – 88.6 nT and 78.5 nT which shows that the RMA gives a more detailed localized view and presents a more uneven deviation in magnetic susceptibility across the area than the TMI (Ndikum & Tabod, 2024). The RMA has also highlighted deep magnetic sources suspected to be faults, dikes and mineral deposits (Njeudjang et al., 2022). The magnetic values are classified as low (< 0.1 nT), intermediate (0.1 nT < RMA < 38.1 nT) and high (>38 nT) magnetic (< 38 nT) and high magnetic (> 38 nT). The negative residual anomalies can be a result of a low magnetization zone and the positive residual anomalies show a possible high magnetization zone. Magnetic high anomaly features in the range of 47.6 to 78 nT, highlighted in pink colour are predominant in the north-east and south-east and also scattered in parts of the area. They are interpreted as signatures of magnetic bodies including fractures, hydrothermal zones and other highly magnetised shallow intrusions beneath the sediments where fluids have altered the magnetic properties of the host rocks, potentially leading to high magnetization. Intermediate residual magnetic anomalies are also scattered around the research area with values ranging from -25.0 nT to 2.1 nT and could be a result of brittle-ductile deformation. This zone can trap magnetic minerals and result in moderate magnetic values. Magnetic low anomaly features in the range of -88.6 nT to -28.8 nT, highlighted in blue colour are predominant in the north-east, south-east and south-west divisions of the map. They are interpreted as signatures result of sedimentary materials in the terrain. The general trending fabric in the map of the residual magnetic anomaly is in the northeast-southwest bearing and a few trending in the northwest-southeast direction of the research area. The fluctuations in magnetic strength values could be due to the compound geologic setting in terms of combination rock type, magmatic activity, hydrothermal vents, and related mineralization, according to the existing geological data and map of the area. The high anomalies are likely to be associated with mineralized zones, such as those found in the vicinity of hydrothermal alteration zones, which are known to host valuable ore deposits. The low anomalies indicate regions underlain by non-magnetic sedimentary rocks, which help outline the boundaries of sedimentary basins and their interactions with adjacent geologic formations.

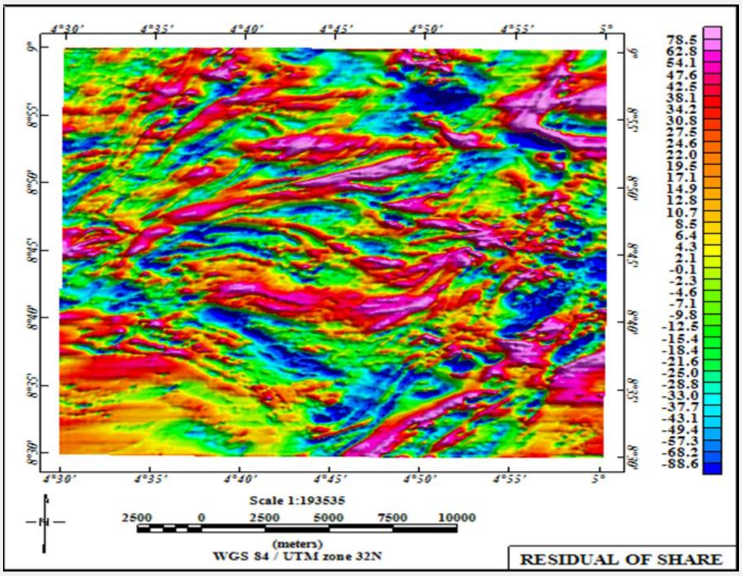

Figure 5. Residual magnetic anomaly map of Share.

Upward Continuation Map

Accentuating the shallow magnetic source depth to a deeper magnetic source depth to enhance the effect of and position of the deep-seated structural objects associated with the basement, the residual grid was raised to a height of 500 m. The magnetic values range from –52.8 nT to 48.8 nT (Figure 6). The high magnetic intensity which is in pink colour has an intensity ranging from 39.6 nT to 48.8 nT which can be a result of magnetic bodies justified in the NE-SW direction. High magnetic values can result from igneous intrusions like dikes, sills, or mafic rocks rich in magnetic minerals such as magnetite. These magnetic anomalies may also indicate hydrothermal alteration, where fluids change the magnetic properties of surrounding rocks, potentially revealing mineral deposits or areas with concentrated mineralization at depth. The low magnetic intensities which is in blue have intensity ranging from -52.8 nT to -18.5 nT which could be as a result of sedimentary terrain The general trending fabric of upward continuation map is in the NE- SW direction and not many in the NW- SE direction of the study area which agree with the trending fabric from residual map. The low magnetic intensities are likely caused by the sedimentary rocks, *su*ch as sandstone or shale, which are generally non-magnetic and cover the underlying more magnetic rocks. The low anomalies may also reflect regions where the basement rocks themselves are non-magnetic or where the deeper magnetic sources have been masked by thick overlying sediments.

Analytical Signal (AnSig) Map

To calculate the analytical signal of the area, preprocessing steps including removal of regional fields, upward continuation to a height of 500 m and grid interpolation to estimate values at missing locations were strictly adhered to. An analytical signal is a vital tool used in estimating the depth of various magnetized bodies in the Share area, and these could be related to hydrothermal alteration vents. It enhances the variations in the magnetization of magnetic sources and highlights peaks of magnetic signatures in the study area. The AnSig map legend of the Share area (Figure 7) shows an amplitude value that ranges from 0.004 nT/m to 0.073 nT/m.

The analytical signal allowed us to divide the Share area into three main magnetic lithologic domains; (i)) a field with peak/ highest gradient with purple colouration ranging from 0.048 nT/m to 0.073 nT/m, which represents boundaries of magnetic sources; some of these high intensities are scattered throughout the study area but dominate the NE and SE parts of Share area; and (ii) a field of in-between high and low intensities ranging from 0.021 nT/m (lowest) to 0.044 nT/m (highest); and (iii) a field with low intensities whose gradient falls within 0.005 nT/m and 0.020 nT/m. The high intensities group can be associated with possible brittle-ductile deformation, faulted granite bodies rich in ferromagnetic bearing rocks such as; (biotite, magnetite, pyrite, mica, migmatite, pegmatite, and amphibole). The high-intensity magnetic anomalies and the associated faulted granite bodies may also suggest significant tectonic activity in the area, which could be linked to regional shear zones or tectonic boundaries. The NE-SW orientation of the magnetic gradients supports the idea of a dominant tectonic fabric in that direction. The low and midway between high and low magnetic intensities can be associated with the possible reflection of down-faulted blocks of the basement complex filled with sediments and can be a result of the possible presence of limestone and sandstone. The analytical map also shows a network of magnetic discontinuities that might stand for fracture zones that could be targeted for mineralization.

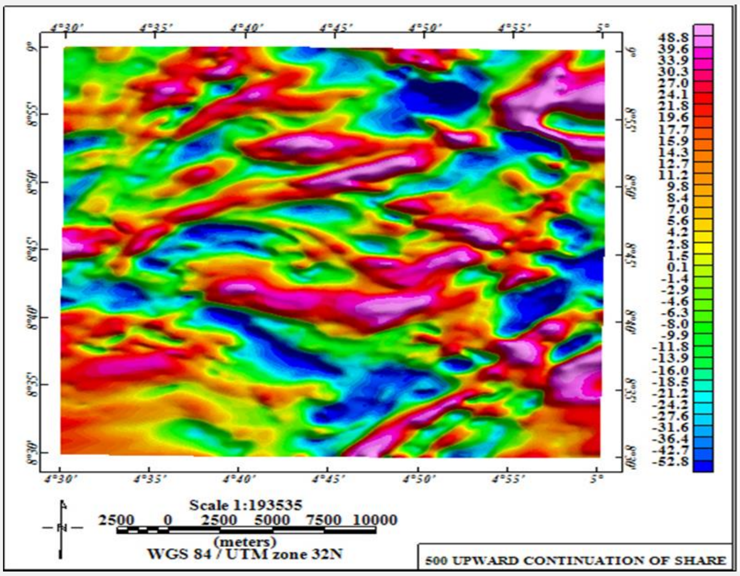

Figure 6. 500 m upward continuation map of Share.

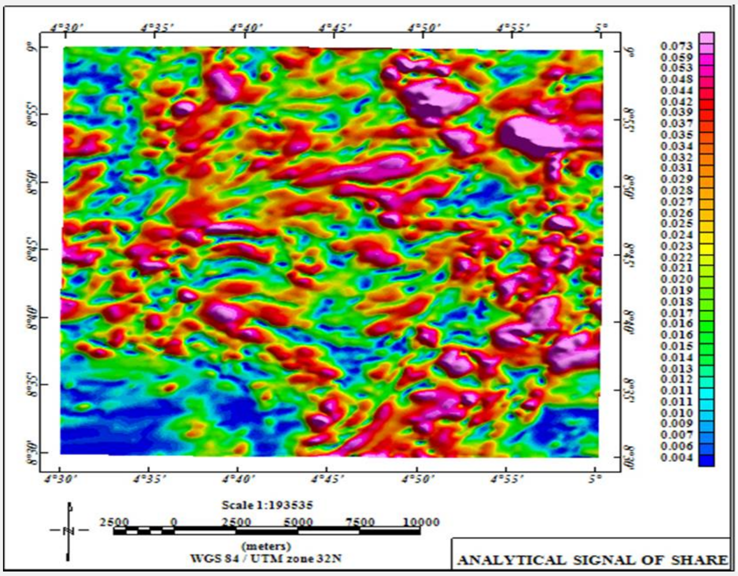

Figure 7. Analytical signal map of Share.

Tilt Derivative Map

Tilt derivatives are usually an effective tool in detecting and mapping the edges of magnetic anomalies which can be related to hydrothermal alteration vents. Its use lies in the fact that tilt derivatives are sensitive to the rate of change of the magnetic field, which is highest at the edges of the anomalies. The tilt derivative trend is majorly in the NE-SW bearing and a few trending in the NW- SE bearing of the research area (Figure 8) demarcate possible edges of geological source bodies like fractures, shear zones and vents related to hydrothermal alterations. The tilt derivative values range from -1.349 rad to 1.374 rad. The high gradient anomalies depicted in pink colour have amplitude ranging from 1.280 rad to 1.374 rad which could be a result of possible geologic contacts or lithological contacts such as fractures or dykes. The low gradient anomalies depicted in the blue colour range from 1.349 rad to 0.778 rad and could be attributed to the demagnetization of magnetic bodies (Zuo et al., 2019). The presence of high gradient anomalies at the edges of these features indicates geological contacts, such as the boundary between different rock types or tectonic zones. These boundaries are often sites of hydrothermal activity, which can lead to alteration and mineralization. Therefore, these areas are potential targets for mineral exploration. The low gradient anomalies suggest regions where the magnetic anomalies have been weakened or altered, potentially due to hydrothermal processes that have reduced the magnetic signature of the rocks. These altered zones could correspond to hydrothermal alteration vents or areas of mineralization, where minerals have been leached or precipitated by circulating fluids.

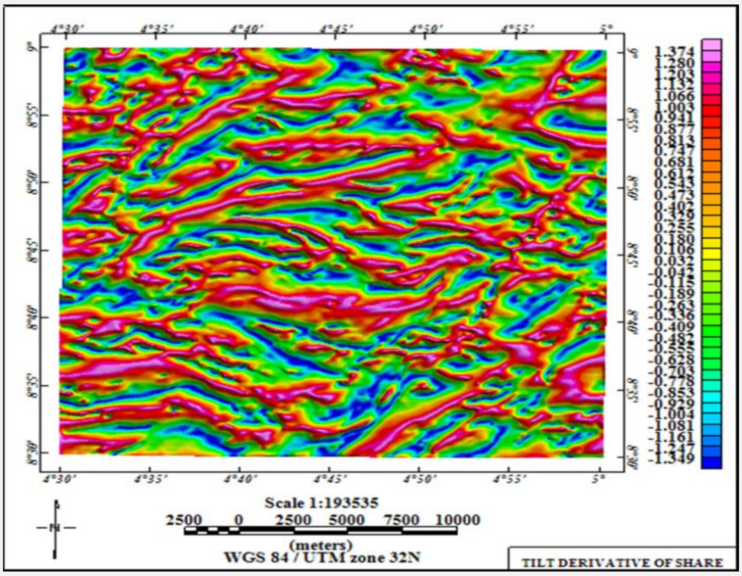

Figure 8. Tilt deritive map of Share.

Source Parameter Imaging (SPI) Map

Processing the residual data grid further, the depth estimate obtained from the result of the SPI map suggests depth estimates from shallow to deep magnetic sources ranging from 287.9 m to 1360.7 m (Figure 9). An inherent guess of the SPI technique claims that the geology is two dimensional representing a contact, thin sheet or horizontal cylinder. The presence of a causative body is assumed to be a 2D contact resulting from a geologic boundary within the area. The highest depth can be found distributed over the entire study area. Parts of the study area in purple colouration show a deep depth of >1202.1 m while some other parts demarcated in blue colouration show a shallow depth from 287.9 m to 437.0 m. This shows the possibility of highly magnetic rocks. The high penetration zones may be attributed to long-term geological processes including crustal faults, hydrothermal zones or tectonic features. These deeper sources may represent fault zones, fractures, or deep magmatic bodies that are potential sites for mineralization and hydrothermal alteration. The shallow penetration depth on the other hand can be attributed to the near-surface geological features such as the shallow sedimentary formation.

First Vertical Derivative (FVD) Map

The FVD map (Figure 10) displays possible geological features such as faults, lineaments, fractures and vents within the zero lines of the map, enabling the identification of possible mineralized zones. The first vertical derivative map shows different magnetic anomalies depicted in pink, red, yellow, green, and blue colours characterized by positive and negative intensities ranging between -

0.040 nT/m and 0.041 nT/m. The regions of higher positive intensity ranging from 0.031 nT/m to 0.041 nT/m are depicted in pink. The intermediate magnetic anomalies range between -0.000 nT/m and 0.031 nT/m depicted in yellow and red. The lower negative intensity (low signal) ranges between -0.040 nT/m and -0.001 nT/m, depicted by blue and green colours. The lineaments have orientation mainly in the NE-SW and NW-SE direction. The presence of high positive frequency may indicate the presence of intrusive bodies which simply means that the region is tectonically active. The low gradient negative intensities could be a result of the presence of low magnetic contents such as limestone and sandstone in the area corresponding to low magnetic signatures. The FVD map was used to generate a lineament map (Figure 11) to show the structures in the area.

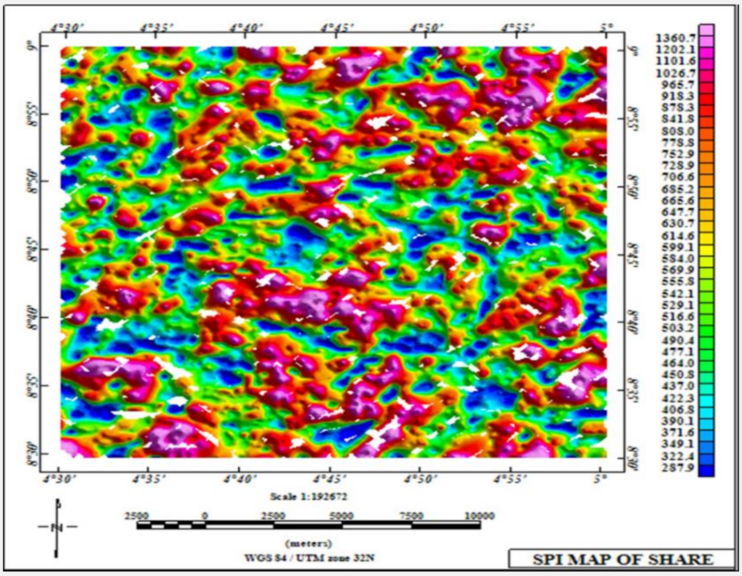

Figure 9. Source parameter imaging (SPI) map of Share.

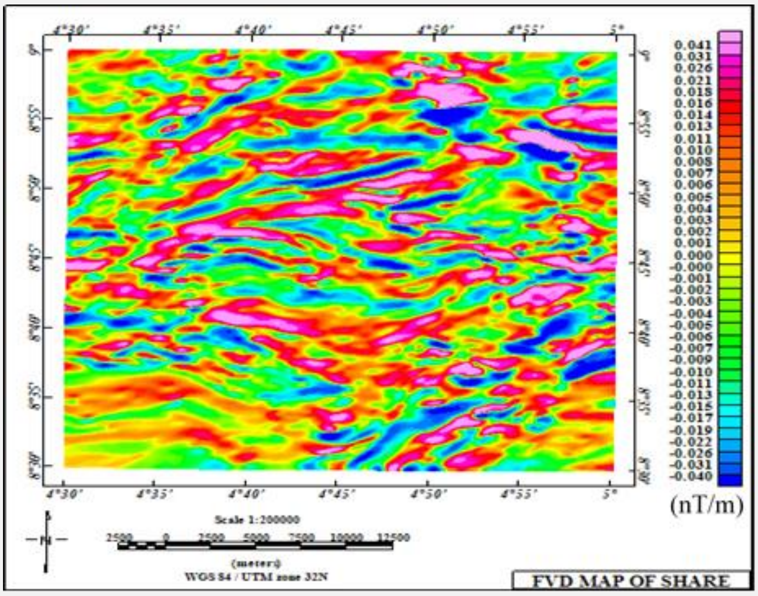

Figure 10. First vertical derivative (FVD) map of Share.

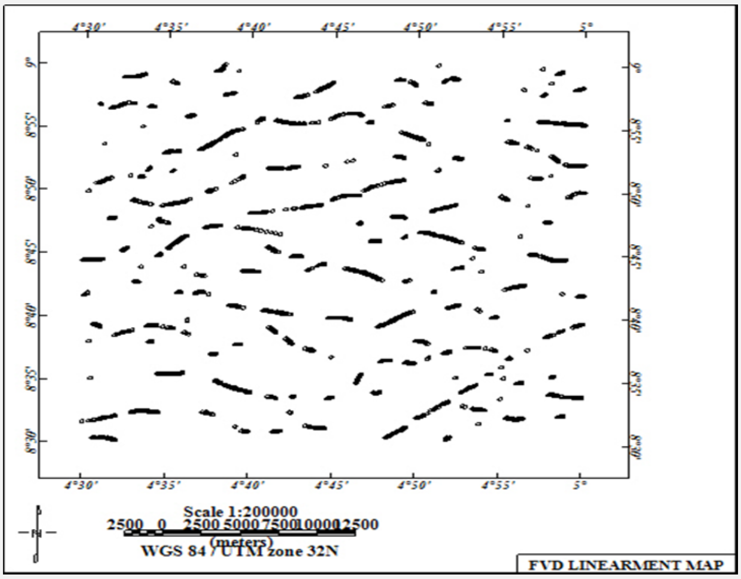

Figure 11. Lineament Map of Share.

Lineament Superimposed on the First Vertical Derivative (FVD) Map

Figure 12 was obtained by superimposing the lineament map (Fig. 11) on the FVD map (Fig. 10) to confirm the area of the geologic structures of the research area. Different magnetic anomalies are depicted in pink, red, yellow, green, and blue colours characterized by positive and negative intensities ranging between -0.047 nT/m and 0.043 nT/m. The areas of higher positive intensity (high signal) range between 0.034 nT/m and 0.043 nT/m and are depicted in pink. The intermediate magnetic anomalies range between 0.000 nT/m and 0.029 nT/m depicted in yellow and red. The lower negative intensity ranges from -0.047 nT/m to -0.001nT/m and is depicted in blue and green colour. The lineaments are confirmed to trend in the NE-SW and NW-SE direction. A set of linear formations that trend NE-SW are located within the contacts within the subsurface which may serve as hydrothermal altered zones.

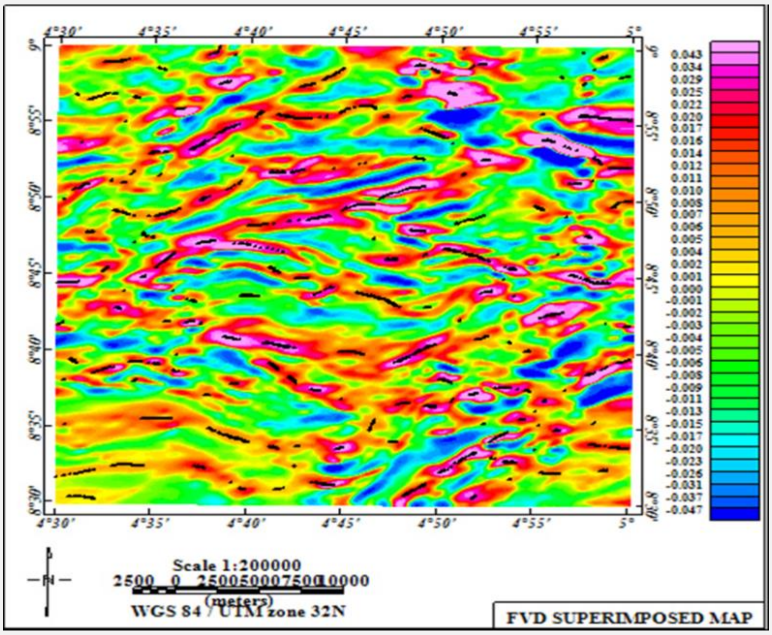

Figure 12. Lineament superimposed on the FVD map of the study area.

CONCLUSION

The analysis of the aeromagnetic data of the Share area, Kwara state, Nigeria was successfully used in delineating the structural/geological features related to hydrothermal vents within the area. The results of the various improvements on the magnetic data in this investigation showed that buried underlying structures linked with hydrothermal alteration zones in Share areas primarily drift in the NE-SW direction, while others drift in the NW-SE direction. The analytical signal map of the Share area has amplitude values that range between 0.004 nT/m and 0.073 nT/m. The low and intermediate magnetic intensities can be associated with the possible basement complex rocks filled with sediments or aged tectonic trends controlling the overlying sediments and can be a result of the possible presence of limestone and sandstone. The high gradient anomalies have amplitude values ranging between 1.280 nT/m and 1.374 nT/m which could be a result of possible geological contacts or lithological contacts such as fractures or dykes and hydrothermal vents. The depth estimate derived from the SPI map reveals depth estimations of hydrothermal vents, brittle-ductile/fracture zones, and ferromagnetic bearing rock zones, ranging from 287.9 m to 1360.7 m. The deep depth in most portions of the research region is greater than 1202.1 m, whereas the shallow depth ranges from 287.9 m to 437.0 m. The FVD map also displayed and improved the image of the observed structural features of the hydrothermal vents, fractures and other lithologic elements in the area with intensities ranging between 0.031 nT/m and 0.041 nT/m. The presence of these high positive intensities indicates the presence of intrusive bodies which simply means that the region is tectonically active.

The exploration of the Share area should focus on regions with high magnetic anomalies, particularly in the central, northeastern, and southeastern parts, which indicate potential magnetite-rich bodies, igneous intrusions, and hydrothermal alteration zones. These areas should be prioritized for field validation through geological mapping, sampling, and geophysical surveys. Faulted zones and shear structures identified in the Tilt Derivative and FVD maps are likely to host mineralization and should be targeted for geochemical sampling and drilling. Shallow magnetic anomalies may correspond to sedimentary formations that could host low-grade mineral deposits, warranting further investigation. High-resolution magnetic surveys should be conducted to refine the delineation of anomalies, guiding more precise drilling efforts. Structural contacts, particularly NE-SW and NW-SE trending faults, are prime targets for exploration as they often facilitate mineralizing fluids. An integrated approach combining magnetic, geochemical, and structural data is recommended to enhance the identification of significant mineral deposits. Ongoing monitoring, trenching, and drilling along key geological trends will refine exploration targets and improve understanding of mineralization patterns. This comprehensive strategy will maximize the potential for discovering economically viable mineral deposits in the Share area, making it a promising site for regional mineral exploration.

Conflict of Intrest Statement

The authors of this manuscript declare that none of us has any known financial conflicts or personal connections that might have appeared to have an impact on the work presented in this publication.

Acknowledgements

We express our gratitude for the precious suggestions by anonymous reviewers and editors, which have greatly helped the improvement of the paper.

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