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Geophysical Delineation of Gold Mineralization Structures Using High-Resolution Ground Magnetic Data in Ilesha Schist Belt, Southwest Nigeria

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Abstract

Ground magnetic surveying was employed to investigate the subsurface geological structures hosting potential gold mineralization in the Itagunmodi area of Ilesha, southwestern Nigeria. A total of 595 data points were acquired across two study sites, along 12 traverses, using a Scintrex ENVI magnetometer at station intervals of 2-5 m. Base stations established proximal to each study site enabled repeated diurnal variation corrections at 30-minute intervals. Acquired data were subsequently filtered to remove cultural noise, excessive interference, and regional magnetic field contributions before processing. Residual magnetic data were processed using Oasis Montaj software, incorporating Reduction to the Equator (RTE) transformation, 3D Euler Deconvolution, and Source Parameter Imaging (SPI) to delineate the depth, orientation, and nature of subsurface magnetic sources. Residual magnetic field maps revealed intensity variations ranging from -276.7 to 290.3 and -263.9 to 232.5 nT for sites 1 and 2, respectively, while RTE map amplitudes ranged from -446.1 to 367.7 and -339.0 to 190.6 nT correspondingly. The 3D Euler Deconvolution analysis, constrained to a structural index of 0.5, delineated subsurface geological features consistent with joints, fractures, and faults, recognized conduits for gold mineralization trending in NW-SE, NE-SW, and N-S orientations. SPI analysis estimated depths to magnetic basement of 1.7-9.5 and 3.0-7.0 m for sites 1 and 2, respectively. The integrated interpretation confirms the efficacy of high-resolution ground magnetic methods for characterizing structurally controlled gold mineralization targets, providing a reliable geophysical survey to guide future exploration and resource evaluation in the Itagunmodi gold region.

Keywords: Gold mineralization; 3D Euler Deconvolution; Source Parameter Imaging; Reduction to the Equator; Oasis Montaj

Highlights

- 590 ground magnetic data points were acquired across two sites
- The data were processed using Oasis Montaj software
- The identified subsurface structures serving as conduit for gold mineralization were fractures, joints, and faults

1.0 Introduction

Gold is a valuable and economic metal that offers significant financial benefits due to its preciousness and stable value. Gold deposits in the Ilesha area are primarily associated with the younger metasediments, particularly the schist belts (Fagbohun *et al.*, 2017; Adekanle *et al.*, 2026). Significant deposits of gold have been identified in the Ife-Ijesha schist belt, specifically at Itagunmodi (Asubiojo *et al.*, 2022; Adekanle *et al.*, 2025), Iperindo (Osinowo *et al.*, 2020), and Ibodi (Kyowe *et al.*, 2024). Other areas with gold occurrences within the schist belt include Ifewara, Ibokun, Ijana and Idoka. Gold deposits in the subsurface occur in two major forms: primary and alluvial. The primary deposits predominantly comprise tiny auriferous quartz veins and strings that have intruded sheared zones within granite gneiss at Iperindo and in amphibolites at Itagunmodi and Ibodi. Fadakinte (2024) reported that the defunct Nigerian Mining Corporation conducted a reconnaissance study in the 1980s, which revealed substantial alluvial gold deposits in Itagunmodi, Ibodi, and Osu.

Primary gold is present mainly as visible gold in quartz veins and embedded in certain ore minerals within various meta-igneous and meta-sedimentary rocks found in the supracrustal rocks of the schist belts. The geochemical processes that produce ore minerals, particularly gold, are structurally controlled (Saniet *et al.*, 2017; Okpoli *et al.*, 2025). Many of the structures that govern mineralization in the Nigerian basement complex are deeply ingrained, making a geophysical approach crucial for defining potential gold exploration and exploitation routes. Structures such as fractures are essential to gold mineralization because they serve as conduits for the mineralization solution and as sites for its deposition (Adekanle *et al.*, 2026; Sani *et al.*, 2017). Globally,

tectonic activity is primarily responsible for the structural arrangement of rocks. Rock folding and fracturing are mostly the result of these natural processes. Over time, geoscientists have developed an interest in basement complex geologic structures because mapping them using geophysical methods will help define depocenters for mineral resources, effective hydrogeology, engineering, and environmental significance linked to the social and economic development of Nigeria (Akinlalu *et al.*, 2016).

Gold was discovered in the Ife-Ijesha schist belt in the 1940s and has since become a significant contributor to Nigeria's annual gold production. The defunct Nigerian Mining Corporation (NMC) identified primary and alluvial gold deposits in some communities along the schist belt in the 1980s. Also, the Ministry of Mines and Steel Development (MMSD) reported that alluvial gold ores in this schist belt account for more than 50% of Nigeria's gross gold output. The alluvial gold deposits of Itagunmodi were formed from the weathered auriferous quartz veins harboured within the metavolcanic rocks (Elueze and Olade, 1985). Metamorphic fluids from metavolcanic rocks leached these gold deposits during the pan-African orogeny, and detailed microscopic analysis showed that small gold specks in the Ife-Ijesha schist belt frequently coexist with sulphide grains (Oyinloye, 2006). These metamorphic fluids originated from metamorphic processes at temperatures exceeding 286 °C (Oyinloye and Steed, 1996).

Researchers have deployed geophysical methods in the Ilesha area for gold exploration. Osinowo *et al.* (2020) employed electrical resistivity tomography to map the potential for gold mineralization in Iperindo, southwest Nigeria's Ilesha schist belt. Conductive zones that were sharp with vertical edges were delineated, indicating the presence of conductive media, such as gold and other related base metals, found in the pegmatite veins. Additionally, Kazeem *et al.* (2021) employed electrical resistivity imaging and induced polarization techniques for mineral investigations in a part of the Ilesha Schist Belt, Southwest Nigeria. Mineral ores were observed as conductive zones in the fault or fractured zones, which agreed with the high chargeability zones observed. In addition, Adekanle *et al.* (2025) used electrical resistivity imaging and induced polarization techniques to delineate zones of gold mineralization at the Itagunmodi area of Ilesha, without accounting for the geological structures that serve as conduits for the mineralization. Their results indicated that areas with high conductivity and chargeability were likely zones of gold mineralization.

The magnetic method is a geophysical tool that has been successfully used in mineral prospecting to identify the magnetic properties of minerals and the structures that determine their localization, as well as in metal exploration to determine the depth to the basement (Ojo *et al.*, 2014; Sani *et al.*, 2017). The magnetic method relies on magnetic susceptibility contrast, making it an effective tool for defining the regional geology of buried basement terrain (Ojo, 2013). Delineating lateral changes in magnetic susceptibility yields insights into structural trends and lithologic changes (Hassanien and Soliman, 2009; Orue and Selim, 2011; Ojo *et al.*, 2014; Oladunjoye *et al.*, 2016; Akinlalu *et al.*, 2016). All rocks, however, are magnetized by the Earth's magnetic field, and the degree of this magnetization depends on their magnetic susceptibility. Nevertheless, the magnetic method provides information that simplifies the location and definition of sedimentary basins where basement rocks are brought close to the surface.

Additionally, this technique is also used to determine the magnetic field's strength in regions where various rock types with differing magnetic mineral contents are present. The method requires measuring the magnetic field magnitude at discrete locations along regularly spaced survey lines throughout the region of interest (Ojo *et al.*, 2020). The vector sum of the Earth's main field, the induced field due to magnetic induction, and other less significant fields arising from cultural influences determines the measured magnetic field magnitude (Adagunodo *et al.*, 2015).

The unprecedented demand and rising price of gold have sparked a rush, with unskilled local miners establishing a mining community in the Itagunmodi area of Ilesha to exploit the mineral and other associated metals (Adekanle *et al.*, 2025). The interest in exploring the Itagunmodi area of Ilesha using ground magnetic methods to delineate other possible mineralized veins within the area that might have embedded gold and other related precious metals was prompted by the success of gold exploitation documented from the various tunnels dug around the vein (Asubiojo *et al.*, 2022; Adekanle *et al.*, 2026). Hence, this research aims to map the subsurface geologic structures of the study area that could act as conduits for gold mineralization using reduction to the magnetic equator, 3D Euler deconvolution, and source parameter imaging. The outcome of this study will provide necessary information to facilitate more organized resource extraction, creating jobs and generating taxes that will support the area's development and aid in improving, planning, and sustainably managing the gold deposits in the Itagunmodi community.

2.0 Location and Geology of the Study Area

Itagunmodi is located on the Ilesha schist belt, situated on the typical basement complex of southwestern Nigeria and within the latitudes 7°28'12" to 7°33'00" N and longitudes 4°37'12" to 4°42'00" E (Figure 1). The schist belt is a metadiorite (Figure 2) and is well known for its abundant mineralization, including gold, gemstones, and other precious stones. The Ilesha belt is a fragment of the Proterozoic succession of the Pan-African mobile belt of western Nigeria (Rahaman, 1976; Klemm *et al.*, 1983). The mineralization, lithology, and structural properties of the schist belt resemble those of the Archaean Greenstone belts, but the portion of lower metamorphic grade, as well as the ultramafic and mafic rock assemblages, is usually noticeably higher (Olusegun *et al.*, 1995; Julius and Adekunle, 2015). The Ilesha schist belt is structurally sliced into two segments by two fractured zones: the Iwaraja faults to the east and the Ifewara faults to the west (Folami, 1992). The western fractured region is primarily composed of amphibolites, amphibole schist, meta-pelites, and meta-ultramafites, whereas the eastern fault is composed mainly of psammitic rocks, supplemented by a few meta-pelites. These assemblages are associated with migmatitic gneisses, a type of gneiss that contains leucosome and melanosome, and predominantly occur on granitic rock formations (Olusegun *et al.*, 1995; Julius and Adekunle, 2015).

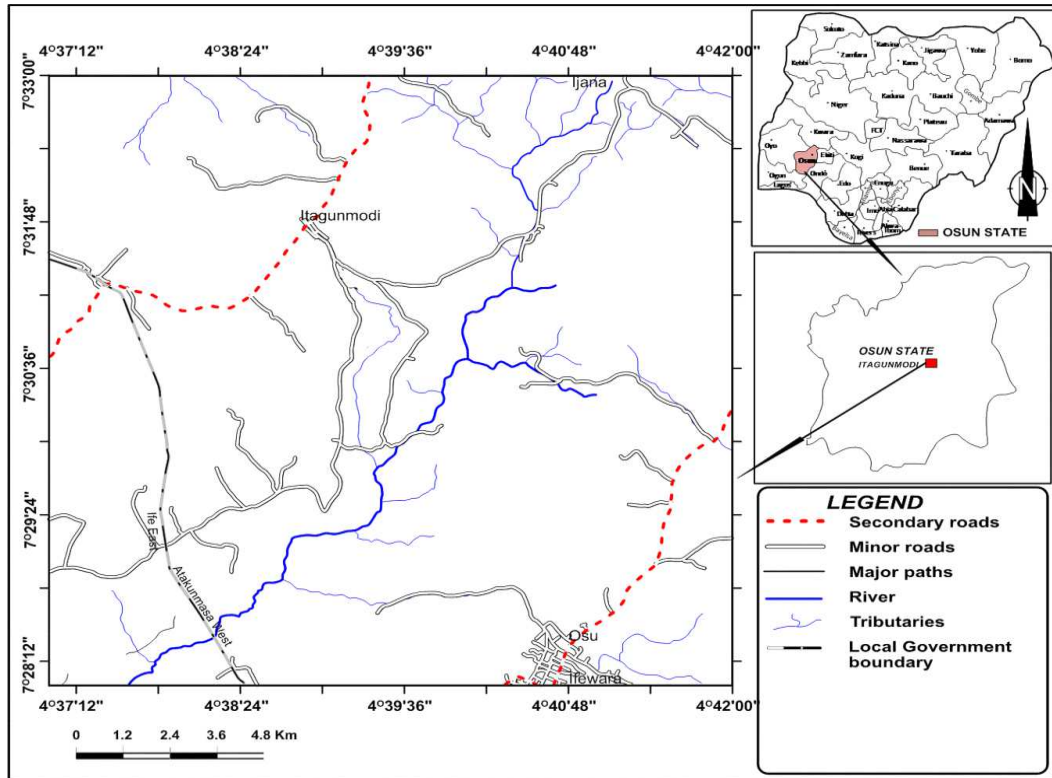


Figure 1: Location map of the study area (Adekanle *et al.*, 2025)

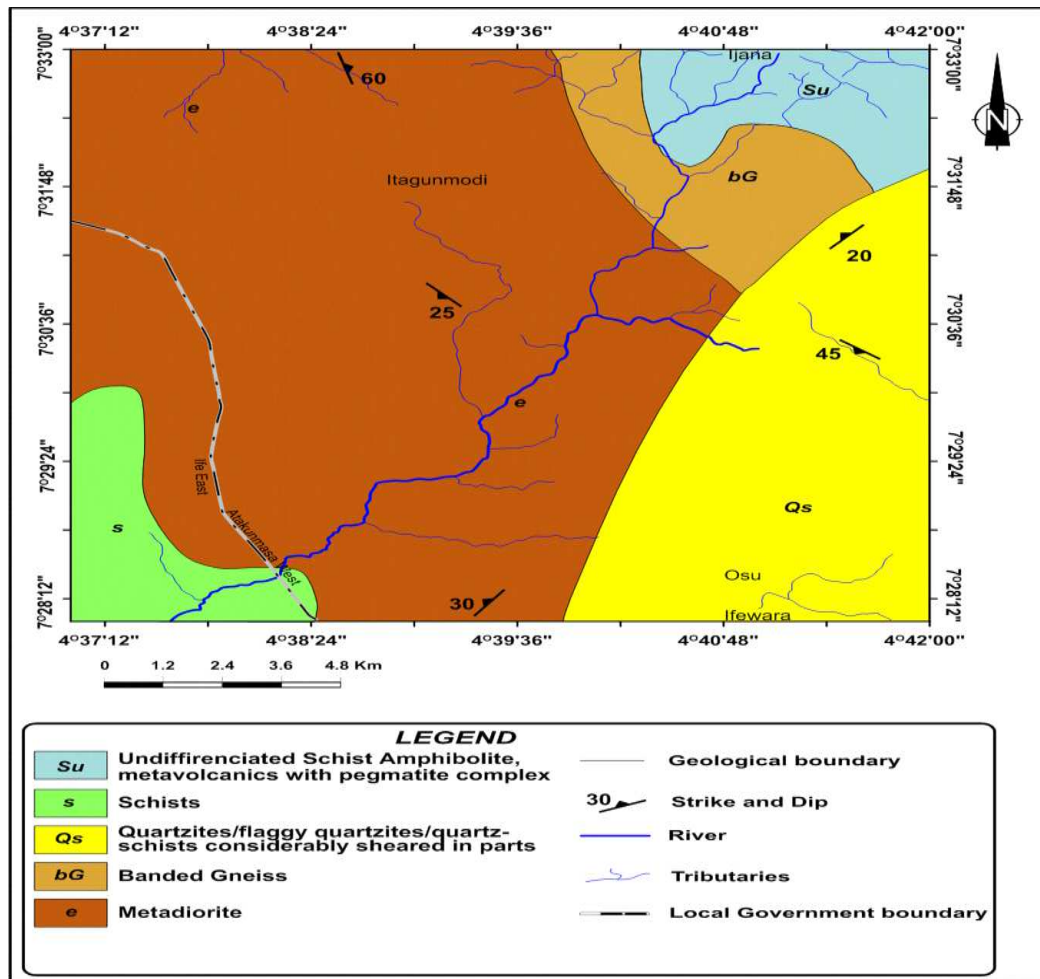


Figure 2: Geological map of the study areas (Adekanle *et al.*, 2025)

According to Elueze's (1981) study, the Ilesha schist belt is divided into the Psammitic sequence, metapelite sequence, and metavolcanic complex. The metapelite sequence consists of amphibolite schist, biotite-garnet schist, and quartz-mica schist, while the metavolcanic complex features lens-shaped intrusions and includes ultramafic and amphibolite rocks, which are located beneath the psammitic and metapelite sequences. The Psammitic sequence consists of quartz and quartzite schist rich in sericite and muscovite. Itagunmodi is an average rural community in southwestern Nigeria, where the number of migrants working on mine fields is quite significant. Agriculture is the primary occupation in the area, and they produce both food crops and cash crops. The study area experiences two distinct seasons: a dry season from October to March and a wet season from April to October (Asubiojoet *al.*, 2022; Adekanleet *al.*, 2025).

3.0 Methodology

This study involved the investigation of the subsurface geological structures at Ilesha area based on the magnetic data qualitative interpretations from the surveys.

3.1 Ground Magnetic Survey

Ground magnetic measurements were taken at two study locations within the Ilesha schist belt using a Scintrex ENVI magnetometer, as shown in Figure 3. The Total Magnetic Intensity (TMI) data were collected along six traverses at each of the two locations, following the directions indicated on the data acquisition maps. Before data collection, base stations were established at each study location in magnetically quiet environments, and data were collected repeatedly at the base stations every 30 minutes to account for the impact of diurnal variations in electric currents in the upper atmosphere or the ionosphere. A total of 595 data points were collected to determine the overall magnetic field intensities along the 12 traverses at the two study locations, with a station interval of 2-5 m.

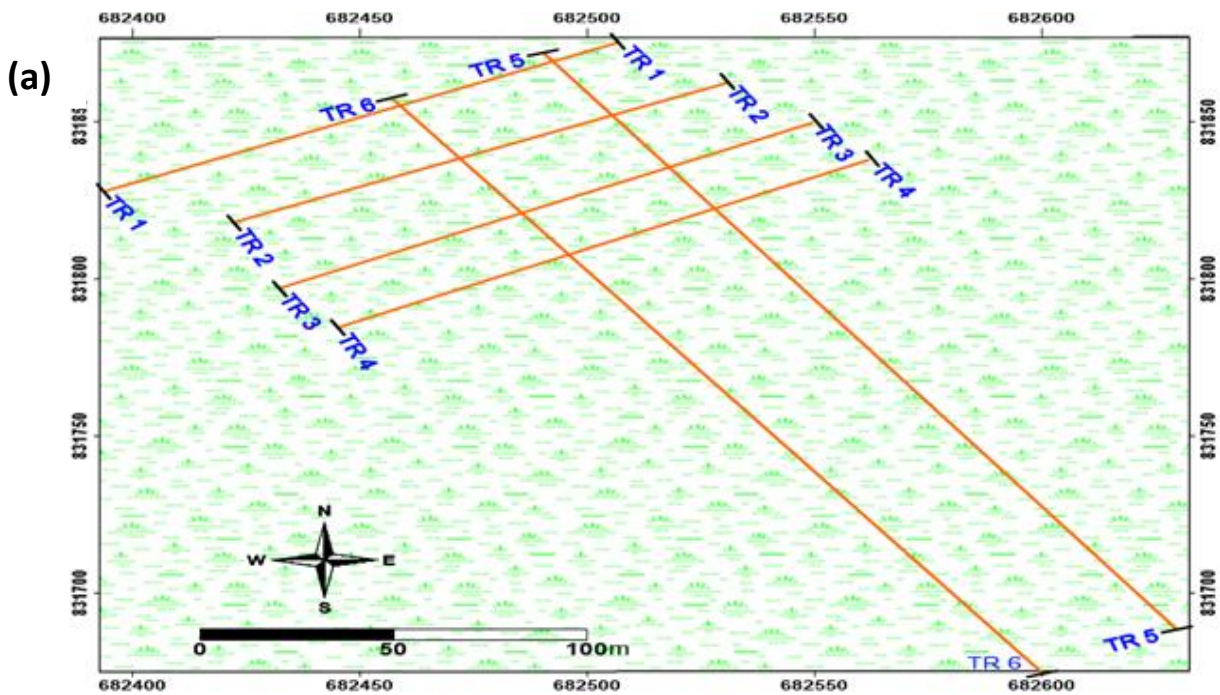
The TMI data were filtered using a Butterworth filter to remove anomalous data attributed to cultural effects and excessive noise, thereby minimizing data noise energy while increasing the signal-to-noise ratio (Odidi *et al.*, 2020). Furthermore, the data were corrected for the regional magnetic field by subtracting the International

Geomagnetic Reference Field (IGRF) value for the study area from each station reading to obtain the Residual Magnetic Intensity (RMI). Also, to remove the asymmetry or uneven distributions of the magnetic anomalies caused by the non-zero magnetic inclination, the filtered magnetic data was reduced to the equator using the Reduction to the magnetic Equator (RTE) filter in the Oasis Montaj Geosoft software (v.6.4.2). The data were also filtered using 3D Euler deconvolution and Source Parameter Imaging (SPI) to the RTE data to enhance near surface features, determine the trends of the structure, and estimate the depth to the magnetic sources. After all data enhancements, the magnetic maps were analyzed both quantitatively and qualitatively to determine the depth to magnetic sources and geological features.

3.1.1 3D Euler Deconvolution

The depth of subsurface magnetic anomalies can be estimated using the Euler deconvolution method for a uniform magnetic field (Nuamah and Tandoh, 2020; Kim *et al.*, 2025). As reported by Olurin (2017), the Euler deconvolution method excels at detecting subsurface contacts and was initially devised to quickly ascertain the position and depth of magnetic or gravity sources. This method operates directly on the data to produce mathematical solutions, without being constrained by geological limitations (Ademakinwa *et al.*, 2020; Nuamah and Tandoh, 2020). Over the years, this method has proven highly efficient at deciphering magnetic data to determine the depths of anomalies directly and their likely source geometry (Barbosa *et al.*, 1999; Roy *et al.*, 2000). The Euler deconvolution technique is frequently used in potential field data interpretation because it does not require prior knowledge of the source geometry (Oyeniyet *et al.*, 2016; Kim *et al.*, 2025). According to Reid *et al.* (1990), the conventional 3D Euler's equation is given by Equation (1).

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



(b)

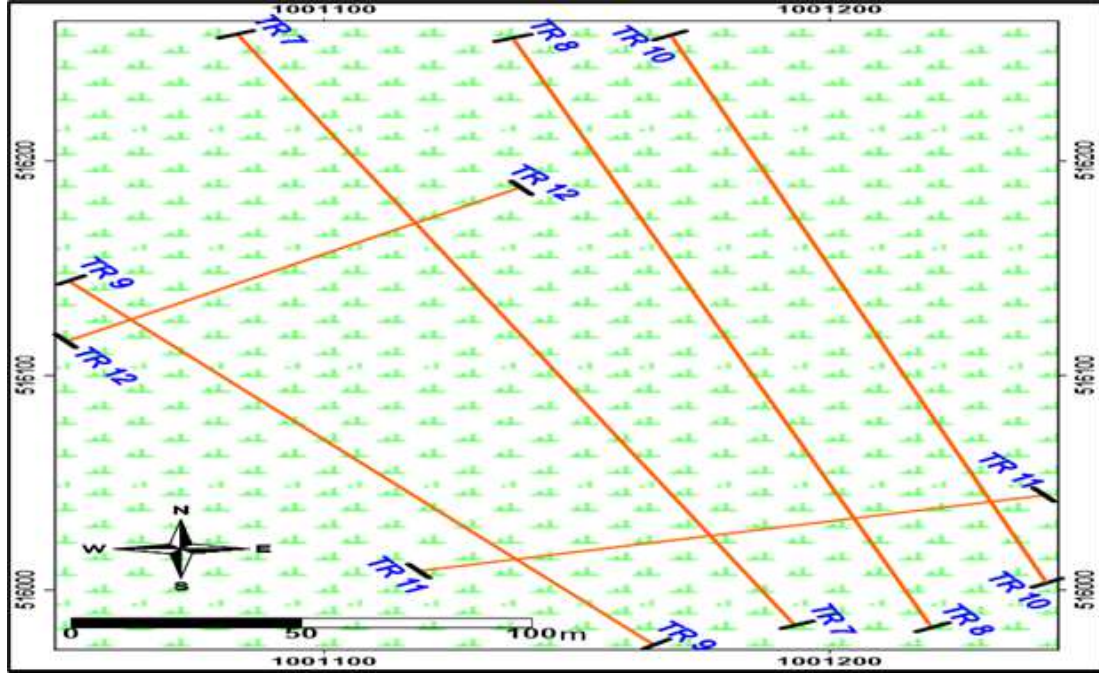


Figure 3a, b: Data acquisition maps for study sites 1 and 2

The source that generates the total field (T), measured at (x, y, z) , is located at (x_0, y_0, z_0) , and the regional value of the total field is B . The most critical parameter in Euler deconvolution is the structural index (n), which is the homogeneity or uniformity factor that connects the source's location to the overall field and its gradient components. The shape and depths of the magnetic anomalous or total field source could be determined by varying n . Incorrect variations in n result in significant biases in depth estimates and a diffuse solution for source locations (Reid *et al.*, 1990; Oyeniyi *et al.*, 2016). The best clustering solution for this study was achieved with a structural index of 0.5.

3.1.2 Source Parameter Imaging

The Source Parameter Imaging (SPI) approach for the calculation of the magnetic sources depths is quick, efficient and reliable (Salako, 2014; Ahmed and Alaa, 2019), and it is based on the complex analytic signal extension to the estimated magnetic depths, also called the local wave number (Odidi *et al.*, 2020). The SPI technique is typically designed for two 2D models, namely the dipping thin-sheet model or sloping contact, which rely on complex analytic signals (Thurston and Smith, 1997; Ndikum and Tabod, 2024). The local wave number for the total magnetic field (T) is given by equation (2).

$$k(x, y) = \frac{\left(\frac{\partial^2 T}{\partial x \partial z} \frac{\partial T}{\partial x} \right) + \left(\frac{\partial^2 T}{\partial y \partial z} \frac{\partial T}{\partial y} \right) + \left(\frac{\partial^2 T}{\partial^2 z} \frac{\partial T}{\partial x} \right)}{\left(\frac{\partial T}{\partial x} \right)^2 + \left(\frac{\partial T}{\partial y} \right)^2 + \left(\frac{\partial T}{\partial z} \right)^2} \quad (2)$$

The maxima k of are not influenced by the magnetic strike, dip, declination, inclination and remnant magnetization, and are situated over the isolated contact edges. The depths to magnetic sources are estimated by taking the reciprocal of the wave number, as given in Equation (3), according to Odidi *et al.* (2020) and Al-Badani and Al-Wathaf (2018).

$$Depth_{(x=0)} = \frac{1}{k_{\max}} \quad (3)$$

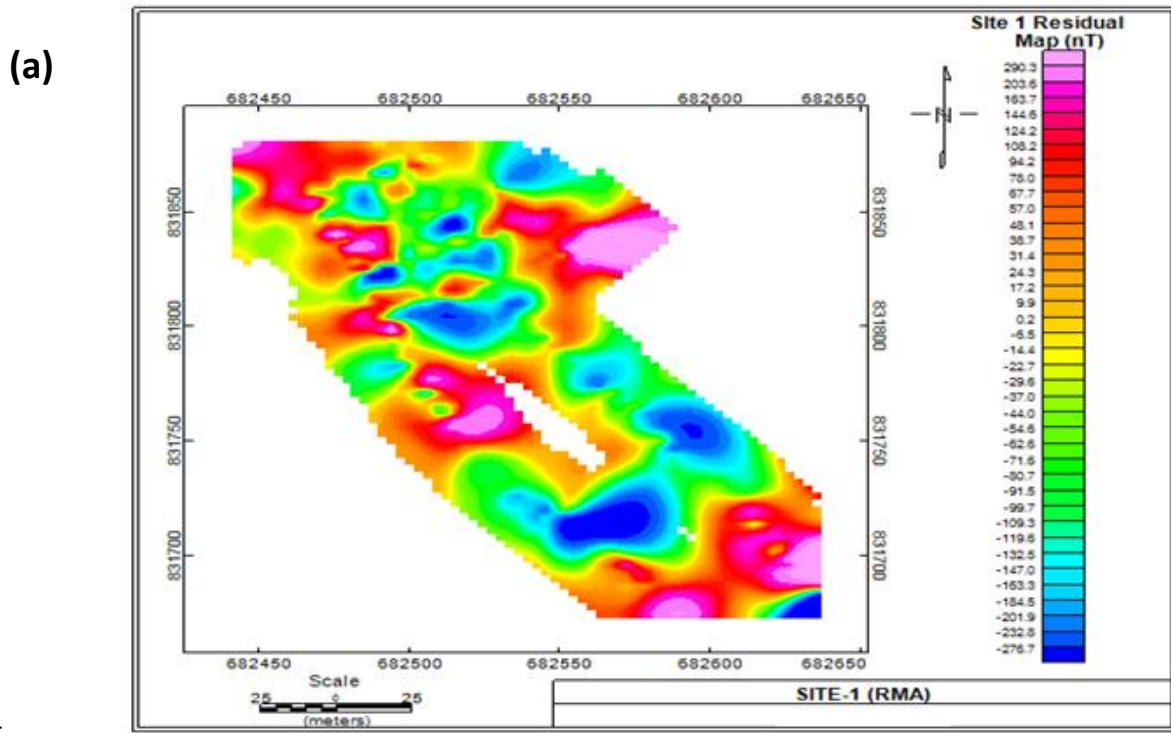
Where $k_{\max}$ is the peak wave number. The SPI function calculates the magnetic source depths with an accuracy of $\pm 20\%$ (Thurston and Smith, 1997; Ahmed and Alaa, 2019; Meneisy and Al Deep, 2021; Ndikum and Tabod, 2024). As indicated in Equation (2), this technique utilizes second-order partial derivatives, which significantly reduces the interference from anomaly features. The source parameters for the magnetic data were obtained

from the gridded data, which serves as the input grids to calculate the susceptibility contrasts, dips, depths, and edge locations of the magnetic sources. The first-order derivatives were considered for this technique, as higher derivatives are more sensitive to noise that could alter the estimated local wave number and magnetic source depths (Al-Badani and Al-Wathaf, 2018). The horizontal gradients of the gridded data were derived using the least-squares technique, while the vertical gradients were derived in the frequency domain. The Oasis Montaj software was used to determine the depth of magnetic sources by analyzing various gridded data that underwent several mathematical processing steps (Odidi *et al.*, 2020; Meneisy and Al Deep, 2021).

4.0 Results and Discussion

4.1 RMI and RTE Anomaly Maps

The RMI maps of the study locations represented the local magnetic anomalies of the Earth's magnetic fields due to the magnetic induction of the magnetic minerals embedded in the shallow depths of the subsurface (Figures 4 a and b). The composite-coloured maps displayed regions with high, intermediate, and low residual magnetic field intensities, ranging from -276.7 to 290.3 nT for study site 1 and from -263.9 to 232.5 nT for study site 2, respectively. According to Bird (1997), the magnetic reliefs of 290.3 and 232.5 nT can be attributed to the depth variations in the magnetic mineral rocks and the disparities in the magnetic contents of the different lithologies. The features of these residual magnetic maps followed similar trends to the total fields, indicating the authenticity of the residual fields. The effects of non-zero magnetic inclinations, which usually cause anomaly distortions and dislocations of targets, were overcome by using the RTE, and the resulting maps are shown in Figures 5 a and b, with magnetic intensities ranging from -446.1 to 367.7 and from -339.0 to 190.6 nT, respectively.



(b)

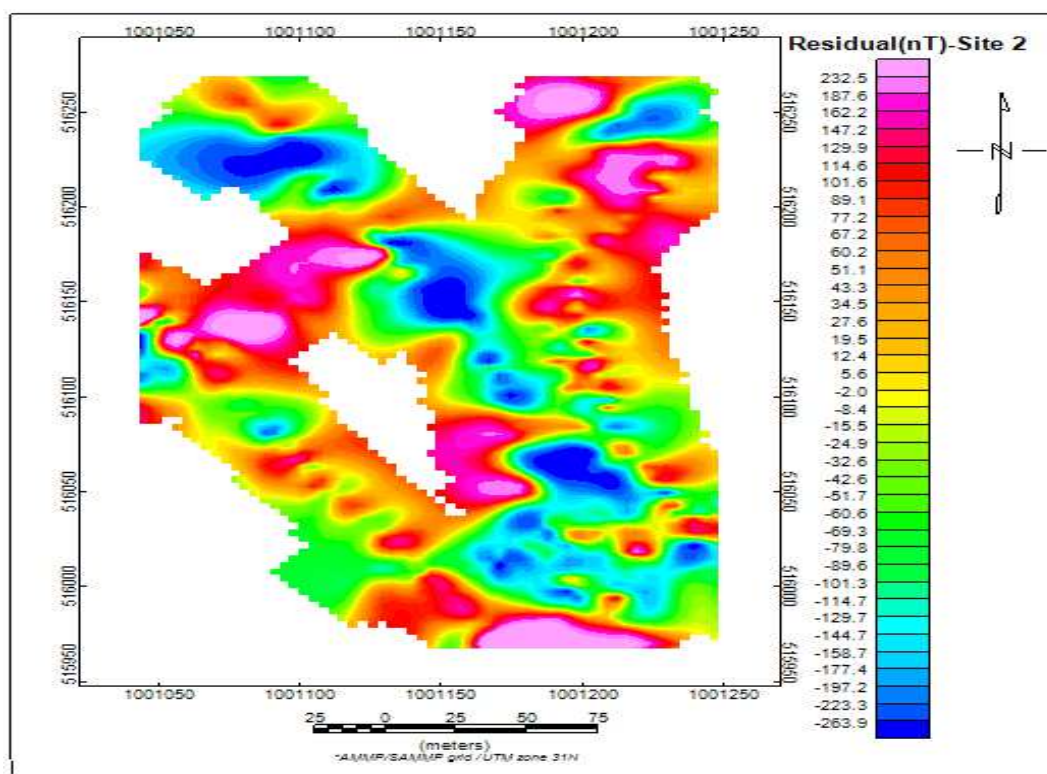
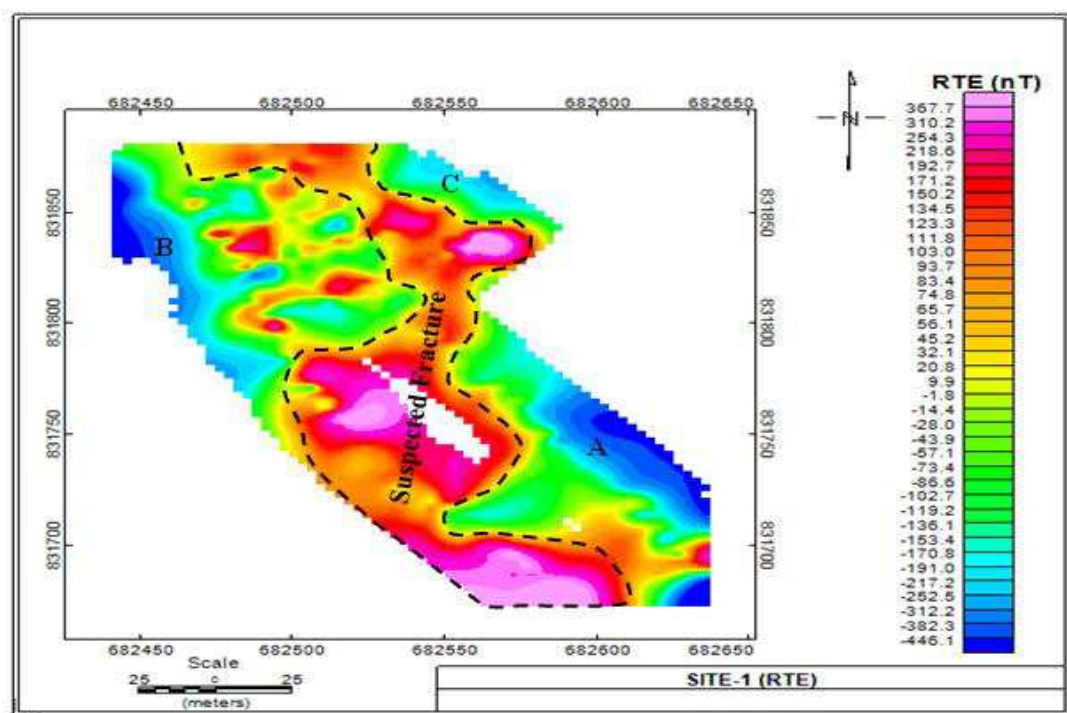


Figure 4a, b: The RMI map of study site 1 and 2

(a)



(b)

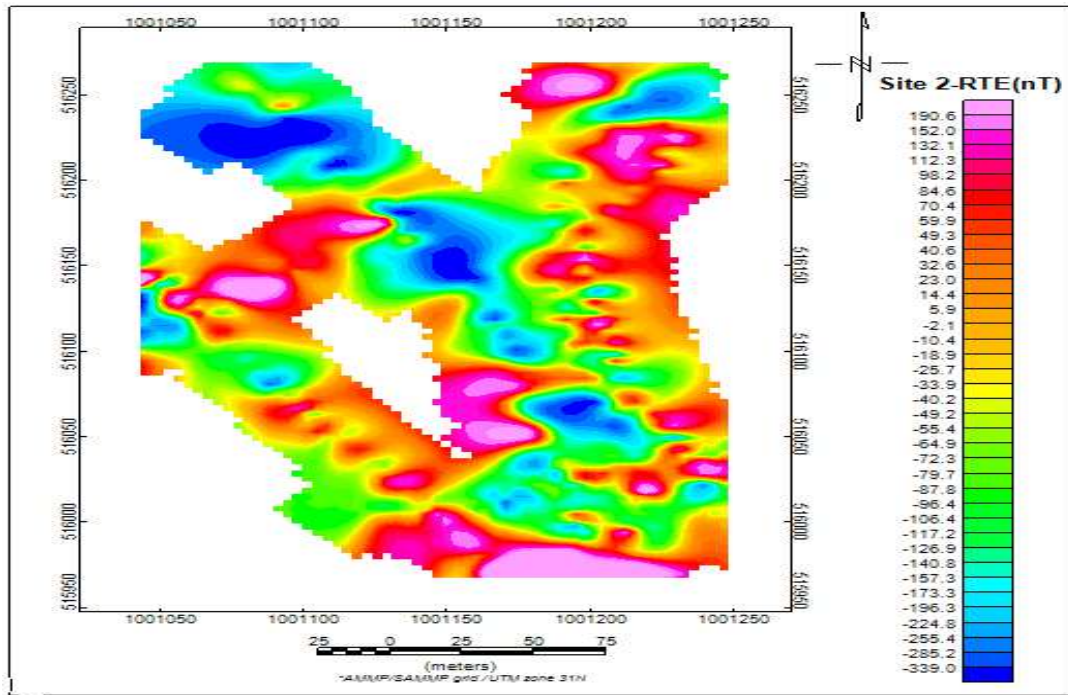


Figure 5a,b: RTE map of study site 1 and 2

The study site 1 map (Figure 5a) revealed fractured zones with high magnetic intensity in the central region, suggesting significant conduits for gold mineralization. The low-magnetic-intensity regions, denoted as A, B, and C, were observed at the edges of the map, except in the southwestern region. Three closures of high magnetic intensities with positive polarities were observed on the map, two of which were broad, irregularly shaped, and had high gradients, trending in a southwestern direction. These regions were primarily defined by closures with moderate magnetic intensities, marked by green patches. Additionally, as observed on the site 2 map (Figure 5b), the central regions were characterized by pronounced high magnetic intensity closures scattered across the map, while regions with low magnetic intensities were visible diagonally across the map. Regions with intermediate gradients are mostly superimposed on those with high magnetic anomalies. The anomalies observed on the maps had different susceptibilities, reliefs, polarities and shapes. The high magnetic susceptibility elongated regions indicated magnetic rock units flanked by subsurface fractured zones or faulting trends, which probably indicate gold mineralization conduits. Similar results were observed by Araffa *et al.*, (2018) in delineating the structural features of the basement complex in the central Sinai area, Egypt, using a magnetic technique.

4.2 Euler Deconvolution and SPI Maps

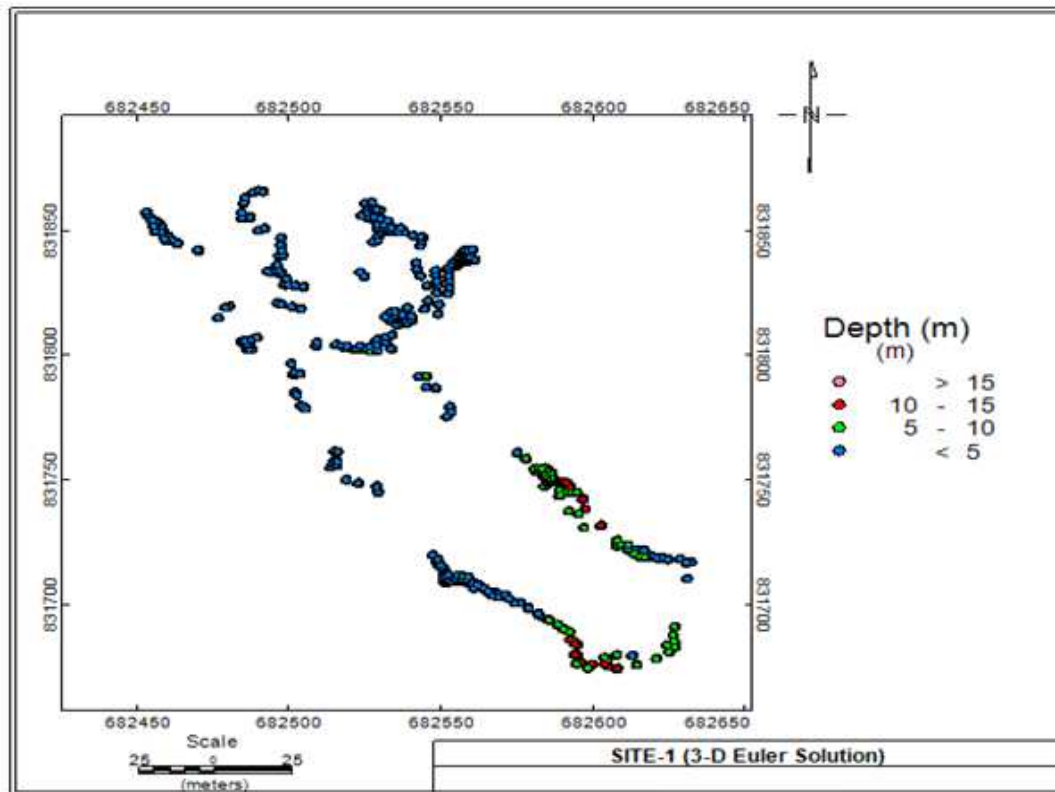
Euler Deconvolution and SPI techniques have been employed over the years to accurately estimate the depths and locations of linear geological features, such as dikes, faults, lineaments, sills and contacts (Reid *et al.*, 1990; Mushayandebvu *et al.*, 2001; Araffa *et al.*, 2018). These methods are used for rapid and large-scale interpretation and application of potential field data. The 3D Euler Deconvolution maps (Figures 6a and b), with a structural index of 0.5, suggest that the identified geological features are joints, faults, or fractures, which are significant conduits of gold mineralization. On the map of Study Site 1 (Figure 6a), the geological features were observed to have NW-SE and NE-SW orientations, scattered across the map. Most of the geological features in the subsurface of site 1 were <5, while other structures with deeper depths between 5 and 15 m were observed in the southern region of the map. The study site 2 map (Figure 6b) revealed NW-SE, NE-SW and N-S trends, and the depths to magnetic sources were mainly at depths below 5 m, with few structures at depths ranging from 5-10 m. The geological structures were not observed at depths above 10 m.

Furthermore, SPI filters were used to determine the depths to magnetic basements on study sites 1 and 2, as presented in Figures 7a and b, respectively. The SPI maps correspond to the residual magnetic maps in Figures 4a and b. On the source parameter map for study site 1 (Figure 7a), the depth to the magnetic basement ranged between 1.7 and 9.5 m. Deep depths ranging from 6.0 to 9.5 m were observed at all edges of the map, except in the northwest parts of the study site. Additionally, low magnetic field depth regions (1.7-2.4 m) were observed scattered around the study site, primarily in the northwest, southwest, and southeast areas on the map. The

source parameter imaging map of site 2 (Figure 7b) showed that the depths to the magnetic sources ranged from 3-7 m, which generally indicated shallow depths. The highest depth of approximately 7 m was observed in the northern region of the study site, while the comparatively shallow depths, ranging from 3 to 4.0 m, were noted in the eastern, western, and northern parts of the study site. The map further revealed that the depths to magnetic sources range from 4.1-4.9 m, primarily in the central region of the study site. The shallow areas observed from the two sites were essentially in agreement with the determination of spectral depth as reported by Salako (2014).

The results of both the 3D Euler deconvolution and source parameter imaging depth techniques agreed with other studies in a similar geological formation in Nigeria. According to Folorunso et al. (2024), the 3D Euler deconvolution technique was used to estimate the residual magnetic anomalies and depths to magnetic sources in the Okeso pegmatites field, southwestern Nigeria. The pegmatites exhibited magnetic susceptibility, a measure of how easily a material can be magnetized, of approximately $4.51 \times 10^{-3} \text{ nT}$, located at depths ranging from 300 to 1200 m, relative to magnetic field sources. The delineation of the subsurface structural geometry and magnetic anomalies depth of Igara Schist Belt, Southwestern Nigeria, using the 3D Euler deconvolution technique revealed that the magnetic sources were majorly embedded at shallow depths of the subsurface between 0 and 300 m, and few of the geological features were at depths above 300 m. (Ozegin and Alile, 2023). The SPI estimated magnetic source depth, according to the study by Odidi *et al.* (2020), ranged between 0.12 and 12.26 km for the aeromagnetic data of central and northeastern Nigeria. In addition, the determination of magnetic source depths using SPI in Niger State, Nigeria, indicated that the depths to magnetic sources ranged from 79 to 5779.3 m (Sunday *et al.*, 2025).

(a)



(b)

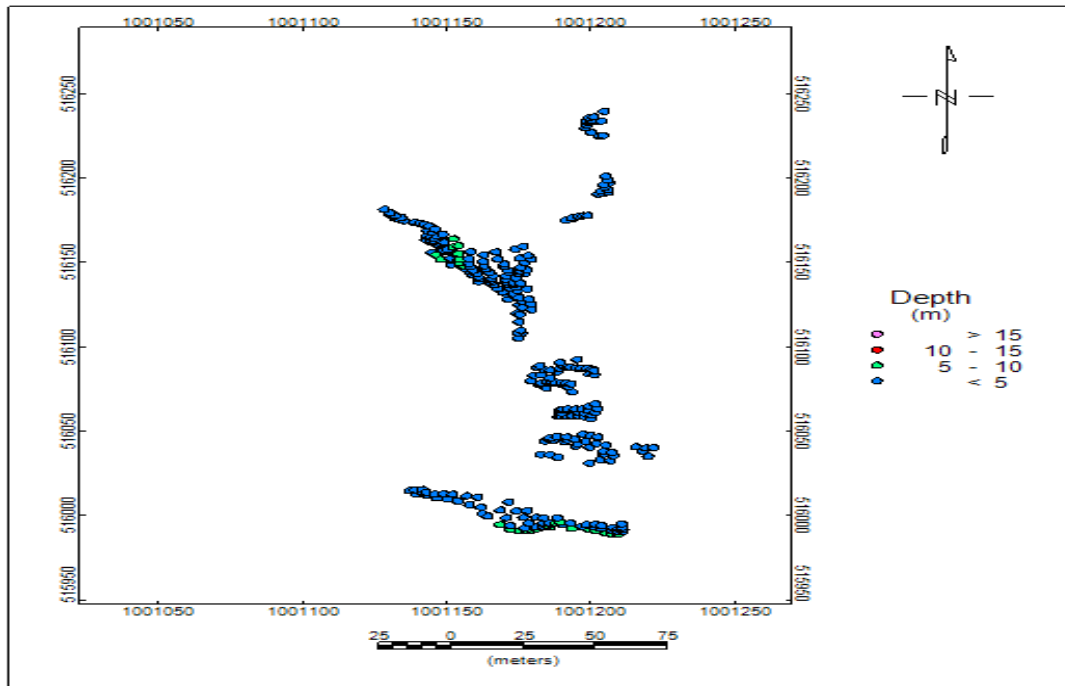
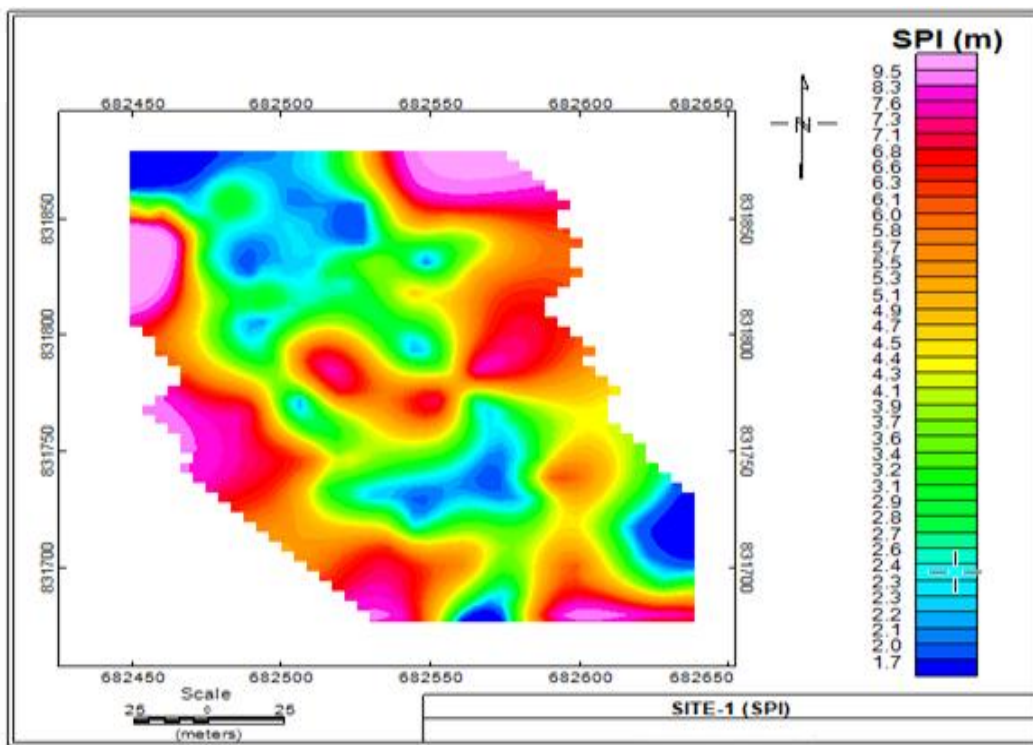


Figure 6a,b: Euler Deconvolution map for study site 1 and 2

(a)



(b)

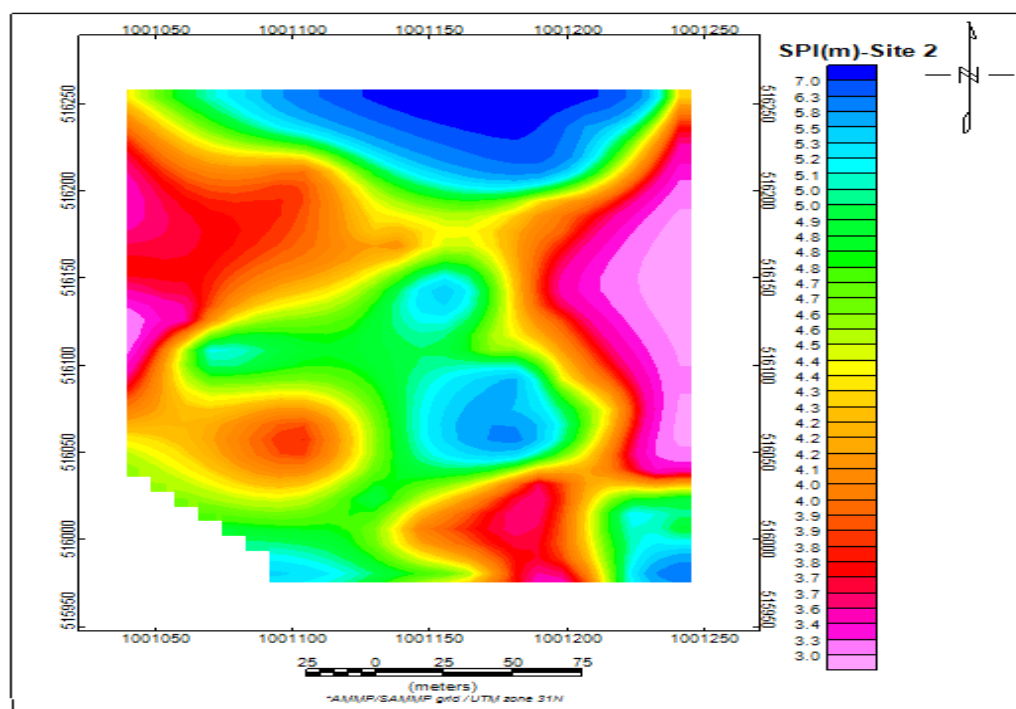


Figure 7a, b: Source parameter imaging map of study site 1 and 2

5.0 Conclusion

This study has demonstrated the effectiveness of high-resolution ground magnetic surveying in delineating subsurface geological structures associated with gold mineralization in the Itaganmodi area of Ilesha, southwestern Nigeria. The integration of Reduction-to-the-Equator processing and 3D Euler Deconvolution successfully resolved the geometry, depth distribution, and structural trends of potential mineralization-hosting features. Magnetic anomalies ranging from -446.1 to 367.7 nT in Site 1 and -339.0 to 190.6 nT in Site 2 revealed significant lithological contrasts and structurally controlled zones characterized by both low- and high-magnetic susceptibility signatures. The identified subsurface structures, interpreted as faults, fractures, and joints, occur at relatively shallow depths of approximately 5-15 m and exhibit dominant NW-SE and NE-SW orientations, with additional N-S trends observed in Site 2. These structural corridors are considered favorable pathways for hydrothermal fluid migration and subsequent gold deposition, highlighting their significance as prospective exploration targets. The consistency between the magnetic anomaly patterns and Euler-derived structural solutions further strengthens the reliability of the interpretations. This research has demonstrated the efficacy of magnetic methods for delineating geological structures that may host gold mineralization.

Conflict of interest

The authors declare no conflict of interest.

Data Availability

Data for this manuscript will be made available upon reasonable request

Funding

The authors declare that no funding was received for this study.

Author Contributions

All authors contributed to the conception and design of the study. Material preparation, data collection, and data analysis were carried out by Adekanle O.J., Badmus B.S., and Ganiyu S.A. The initial draft of the manuscript was prepared by Badejo A.A and Ojo A.O, while Sedara S.O and Solomon M critically reviewed and provided valuable comments on earlier versions of the manuscript. All authors read and approved the final version of the manuscript prior to submission.

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