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Qualitative and quantitative interpretations of high-resolution aeromagnetic data of Saki-East area, for basement and structural framework

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Abstract

Earth tremor is a small seismic event that occurs in seismically unstable region. However there have been little information about the earth tremor before 1987, but events between 1990 and 2000 have triggered further research. This study is aimed at qualitatively and quantitatively interpret high-resolution aeromagnetic data of the Saki-East area to provide the basement and structural framework of the area. The aeromagnetic data of the study area consisting of Igboho data sheet 200 and Lechilaku sheet 221 were processed using Oasis Montaj software and interpreted for mapping basement and structural stability in the area. The enhancement process was further carried out on the data to generate residual aeromagnetic data used in determining the lineament orientations in the study area. 3D Euler deconvolution and Source Parameter Imaging techniques were employed to determine basement depth of subsurface geological structures. The result shows a positive correlation with geologic structures: 3D Euler solutions for SI = 1 show large clusters depicting geological bodies associating with faults. The magnetic basement depth from 3D Euler and SPI shows over 90% dominance of the shallow depth range of 3-600 m in the study area; this revealed that the dominant shallow depth of the magnetic basement causes the faulting system of the study area to become weak zones through which tremor occurs. Lineaments in the study areas are classified into major and minor lineaments, the major lineaments are prominent within the basement rocks and are possibly produced by the regional historic orogenic movement that affected Nigeria basements.

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1. Introduction

An earthquake, otherwise known as a tremor, is a shaking of the surface of the earth as a result of the sudden release of energy in the earth's crust; it mostly occurs at the boundary plate. It can also be regarded as plate motion produced when stress within the earth exceeds the rocks' strength at its weakest points or rapid release of stored elastic strain in the lithosphere in the form of sudden movement of portions of the earth's crust along faults [1, 2]. These plate movements are as a result of tremendous forces applied

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at the boundary, while the tremor occurrence takes place at the plate boundaries along belt-like zones (seismic belt). However, the Sake-East area in southwestern Nigeria is not situated along any belt-like zones but located at the eastern Atlantic Ocean, which is consistently diverging. Because this area is not associated with any tectonic events and normally quiet, there has not been any record of devastating earthquakes in the country, but there had been occurrence of earth tremors between year 1933 and 2000 (in which three different once occurred in one year), especially in southwestern Nigeria. These tremors show that Nigeria may not be as aseismic as previously thought, but there can still be a possibility occurrence.

Several authors have researched earth tremors [3, 4]. Ref. [5] reported the 28 July 1984 southwestern Nigeria earthquake and its implication for the understanding of the tectonic structure of Nigeria. A maximum epicentral intensity of six was assigned to this tremor on the basis of the macroseismic effects and was located near Ijebu-Ode. According to them, three aftershocks were recorded in quick succession within twenty minutes, and they were linked with tectonic activities of Atlantic fractures that extend into the Nigerian landmass. Ref. [6] carried out an investigation of the structural stability of the subsurface of the Ibadan area against Earth tremor using aeromagnetic data. The data were further processed using THDR to obtain the lineament orientations, which revealed the percentage of lineaments Orogenies in the area. The research concluded that the Ibadan area is not immune from experiencing tremor occurrence. Ref. [7] carried out an earthquake offshore southwestern Nigeria where it was shown that the fault that triggered the tremor ruptured at about 10 km within the upper crust local magnitude of 4.5 and moment magnitude (Mw) of 4.1. The epicentre of the earthquake lies very close to the fracture zone situated between the Romanche and Chain fracture zones, an extension of the Atlantic fracture zone into the continent. Ref. [8] researched seismic occurrence between 1990 and 2009 in the mid-Atlantic fracture zones (between Latin America and west Africa). The analysis of the data showed that the epicentral locations of the majority of the earthquakes were along, the Romanche and Saint Paul fracture zones. The focal depth of the earthquakes recorded is 10 km, and their body wave magnitudes range from 3.5 to 6.3, with magnitudes ranging from 4.0 to 4.4 and from 4.5 to 4.9 being dominant, having 246 (36%) occurrences each. The result of b-values over two decades suggested that there was no likelihood of an earthquake with a surface wave magnitude > 7.0 before 2019. Ref. [9] investigated a lineament study over part of the Ado-Ekiti region using aeromagnetic data. The study shows that various filtering methods, such as reduction to pole, analytic signal, first vertical derivative, and first horizontal derivative, were applied to the residual magnetic intensity. These filters helped to define lithological boundaries, intersections of geological structure, faults, folds, and contacts. Reduction to the pole varied from -213.1 to 314.1 nT, upward continuation at 100 m ranged from 156.1 to 142.4 nT, and the analytical signal varied from 0.0 to 0.4 nT. The magnetic intensity distribution was found to depend on the size, depth of burial, and thickness of low -susceptibility superficial material overlying the magnetite-rich crystalline rocks. The tilt derivative proved very useful in the delineation of lineaments, which were in the form of contact, faults, folds, and joint derivative maps.

The orientation of several geologic features at the basement level provides information about the stability of that region, the earth tremor experienced in Saki between 2016 and 2022 could be alluded to the arrangements of geologic features such as faults. High-resolution aeromagnetic data was considered to be used for the qualitative and quantitative interpretation of the saki East subsurface for both structural and basement mapping. However, the aim of this paper is to apply different techniques to the Saki East area using an aeromagnetic survey to evaluate subsurface geologic sources, revealing the structural complexity of the region, and identify disaster-prone areas for decision-making. The correlation between the linear color method and the equalized histogram method was also noticed.

1.1. Location and geology of the study area

The study area is the Saki East area of Oyo State, Southwestern Nigeria, comprising of two aeromagnetic data sheets (Igboho sheet 200 and Lechikalu sheet 221). The area is about 110 km in length, about 55 km in breadth, and 6050 km^2 in ground surface (Figure 1). The geographical coordinate is between 555900 mE and 611000 mE of longitude, while the latitude is from 883100 mN to 993100 mN. It is geologically made of the migmatite-gneiss complex (MGC), the schist belt (metasedimentary and metavolcanic rocks), and the older granites (Pan African granitoids) petrolithological unit of the Nigerian basement complex. Specifically, the rocks of the schist belt petro-lithological unit in this study area belong to the Iseyin-Oyan River schist belt. The geological map of the study area acquired from the Nigerian Geological Survey Agency shows that few faults were mapped through geological framework surface mapping (Figure 2). This is probably due to the lack of surface expression of the faults, which might have been concealed majorly by geologic processes such as weathering, erosion, and sedimentation. This was supported by Ref. [10] who stated clearly that the Iseyin-Oyan River schist belt, which is one of the three major petrolithological units of the Nigerian basement complex in the study area, is generally poorly exposed, and structural data are sparse.

2. Materials and methods

2.1. Methodology

An aeromagnetic survey in southwestern Nigeria was conducted and completed around August 2009 by Furgo Airborne Survey limited, USA, through which the data over southwest Nigeria was acquired using a proton precession with a resolution of about 0.1 nT at 80 m attitude with flight and line spacing of 500 m and 5000 m, respectively [11–13]. These data acquisitions by Furgo include

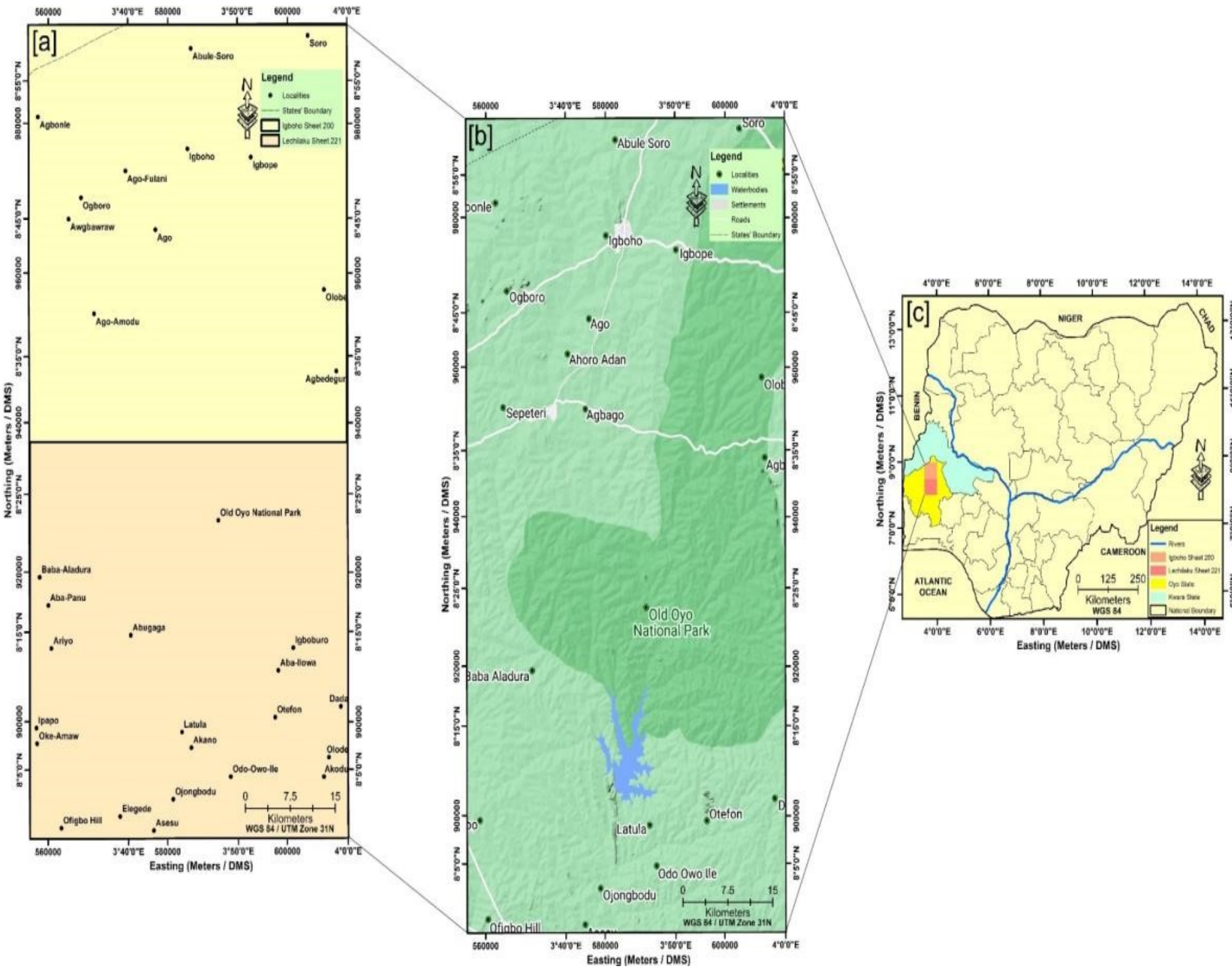

Figure 1: Location of the study area. (a) index map of the NGSA aeromagnetic sheets covering the study area; (b) Google map of the study area showing its accessibility by roads; (c) map of Nigeria showing the states covered by the study area.

Igboho sheet 200 and Lechilaku sheet 221 (the study area) acquired from the Nigeria Geological Survey Agency. The field acquired data were in x- (longitude), y- (latitude) and z- (TMI) Microsoft Office Excel format and were further transported into Oasis Montaj software. The x and y values were converted to geographic coordinates. A grid cell size of 100 m and minimum curvature technique were used to produce the corrected total magnetic intensity (TMI) map of the study area (Figure 3), and were then considered for filtering operation to improve its quality for better understanding. An algorithm developed by the Centre of Exploration Targeting in Australia, which has already been incorporated into Oasis Montaj software, can be used in extracting lineaments associated with study locations. The purpose of this is for identification of lineaments and structural complexity areas. These lineaments extracted were plotted as a Rose diagram.

2.2. *Reduction to the equator (RTE)*

Reduction to the equator is used in low magnetic latitudes because it makes the magnetic field of the Earth and magnetization of the magnetic sources appear horizontal and also centers the peaks of magnetic anomalies over their sources. This can make the data easier to interpret while not losing any geophysical meaning [12, 15–18]. The RTE maps were generated using the geomagnetic inclination and declination of -7.8° and -1.38°, respectively from IGRF calculation for a position (X – 3.71°, Y – 8.74°) for the Igboho sheet and the geomagnetic inclination and declination of -9.09° and -1.47°, respectively, from IGRF calculation for a position (X – 3.67°, Y – 8.25°) for the Lechilaku sheet.

2.3. *Regional residual separation*

This is the process of separating the magnetic effects due to deep seated sources known as the regional from the magnetic effects due to shallow sources known as the residual to focus on that of interest. The field continuation method, among other methods (such as graphical residualizing, surface-fitting residualizing methods, empirical gridding methods, and second vertical derivative

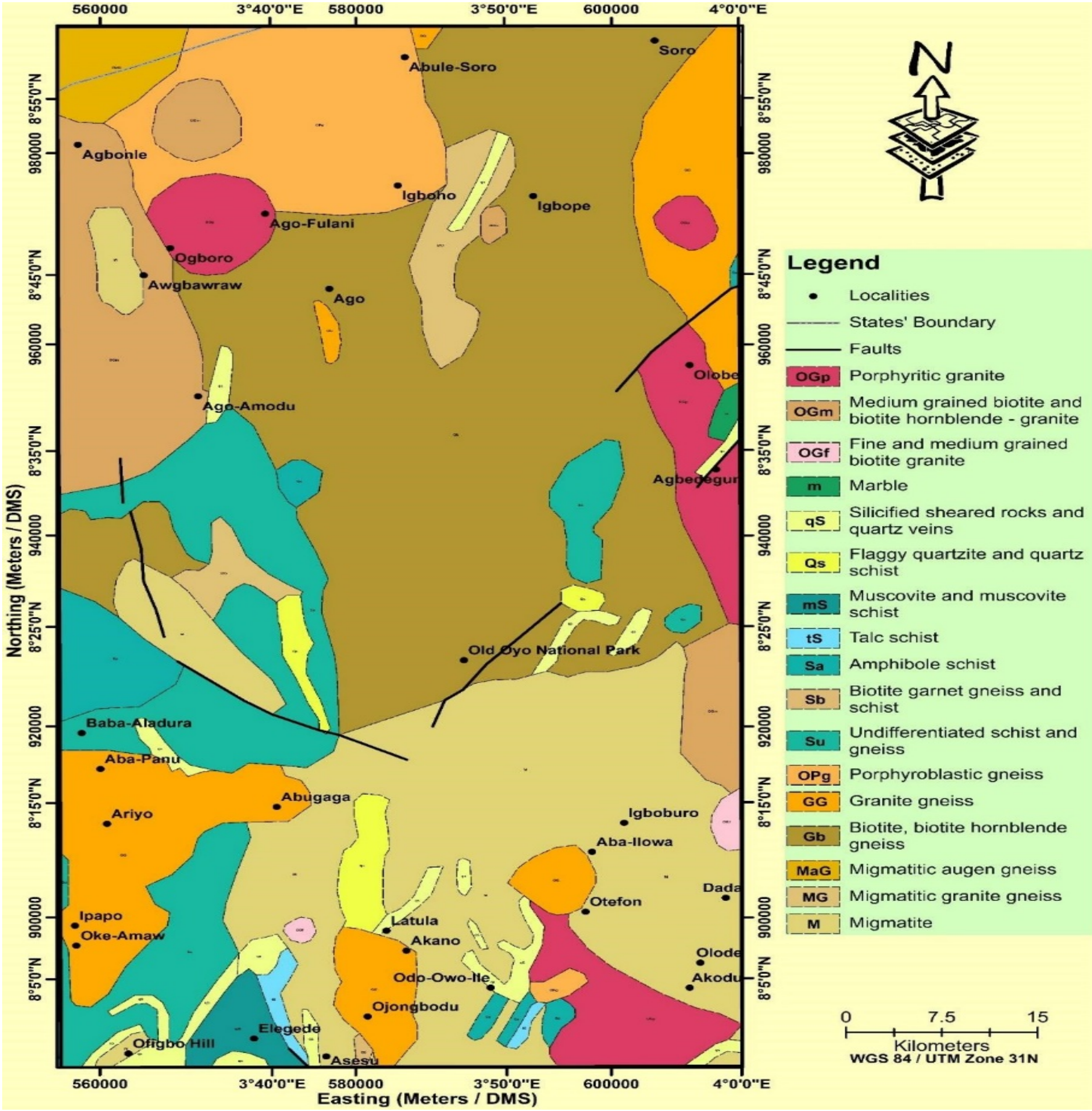

Figure 2: Geological map of the study area [14].

methods), is used to isolate the regional and residual components from the RTP map. The Fast Fourier transformation is used in this procedure.

3. Result and discussion

3.1. Total magnetic intensity (TMI)

The results of the corrected Total Magnetic Intensity (TMI) maps of the study area are presented in linear color and equalized histogram (Figure 3). These maps depict a visual representation of the aeromagnetic data of the Saki East area, which includes Igboho sheet 200 and Lechilaku sheet 221. The TMI values range between -192 nT and 209 nT for Igboho (Figure 3a), and from -409 nT to 187 nT for Lechilaku sheet 221 (Figure 3c). Figures 3b and 3d amplified the very little and non-obvious contrast in magnetic intensity values in Figures 3a and 3c to become noticeable. These amplifies magnetic intensity contrast depicts three (3) distinct zones in the study area – the high magnetic intensity zone (red/pink color) dominated in the study area (Figures 3b and 3d), the intermediate magnetic intensity zone (green color), and the low magnetic intensity zone (blue color). The observable general trends of magnetic anomalies on the TMI histogram equalization maps of the study area are approximately NE-SW and NW-SE (Figures

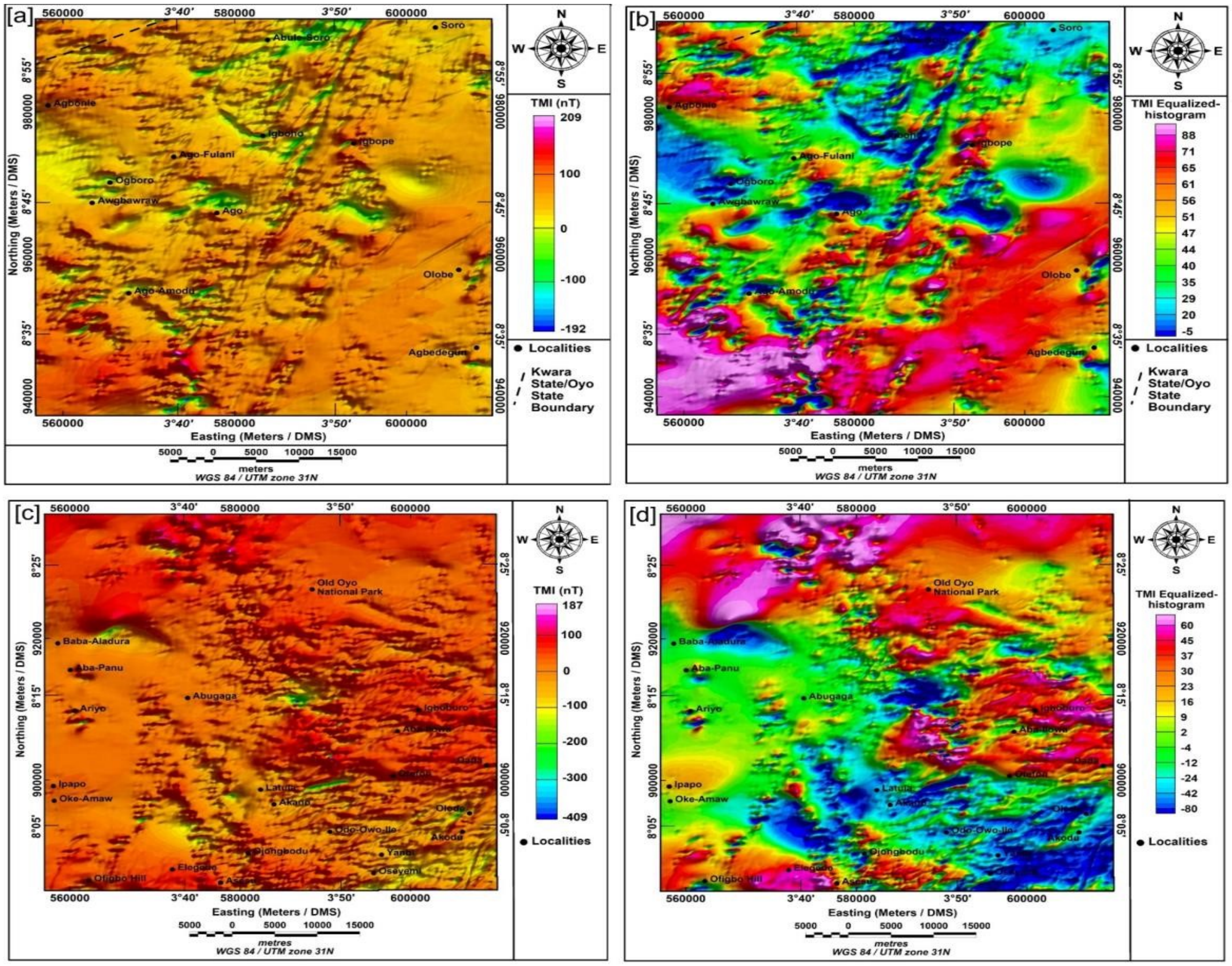

Figure 3: Corrected Total Magnetic Intensity (TMI) maps of the study area. (a) Igboho linear color, (b) Igboho equalized histogram color, (c) Lechilaku linear color, (d) Lechilaku sheet 221 equalized histogram color.

3b and 3d), which have been widely identified within the Nigerian basement complex [19, 20] and agree with observed geological trends on the geological map of the study area (Figure 2), thereby giving credibility to the aeromagnetic data and its applicability in extracting the geological information, particularly the fault architecture of the study area.

3.2. The reduced to equator (RTE)

The RTE map of the corrected TMI data of the study area is presented as color shaded relief maps using the linear color method and the histogram equalization color method (Figures 4a-d). The RTE aeromagnetic anomaly amplitude of the Igboho sheet ranges from -92 nT to 171 nT (Figure 4a), while the Lechilaku sheet ranges from -203 nT to 150 nT (Figure 4c). In the similitude of the corrected TMI maps (Figure 4), the RTE aeromagnetic anomaly maps of the study area using the linear color method (Figures 4a and c) show very little to no obvious significant contrast in the distribution of anomaly amplitude due to a narrow range of magnetic intensity values in the study area. However, the RTE aeromagnetic anomaly maps of the study area using the histogram equalization color method (Figures 4b and d) has amplified the very little or non-obvious contrast in magnetic intensity values in Figures 4a and c to become noticeable. The amplification of the magnetic intensity contrast using the histogram equalization maps (Figures 4b and d) depicts three distinct zones of magnetic intensity in the study area – the high magnetic intensity zone (red/pink color), the intermediate magnetic intensity zone (green color), and the low magnetic intensity (blue color zone). The observable general trends of magnetic anomalies from the TMI histogram equalization maps of the study area are approximately NE-SW and NW-SE, which have been widely identified within the Nigerian basement complex [19, 20], and agree with observed geological trends on the geological map of the study area (Figure 2), thereby giving credibility to the aeromagnetic data and its applicability in extracting the geological information, particularly the fault architecture of the study area.

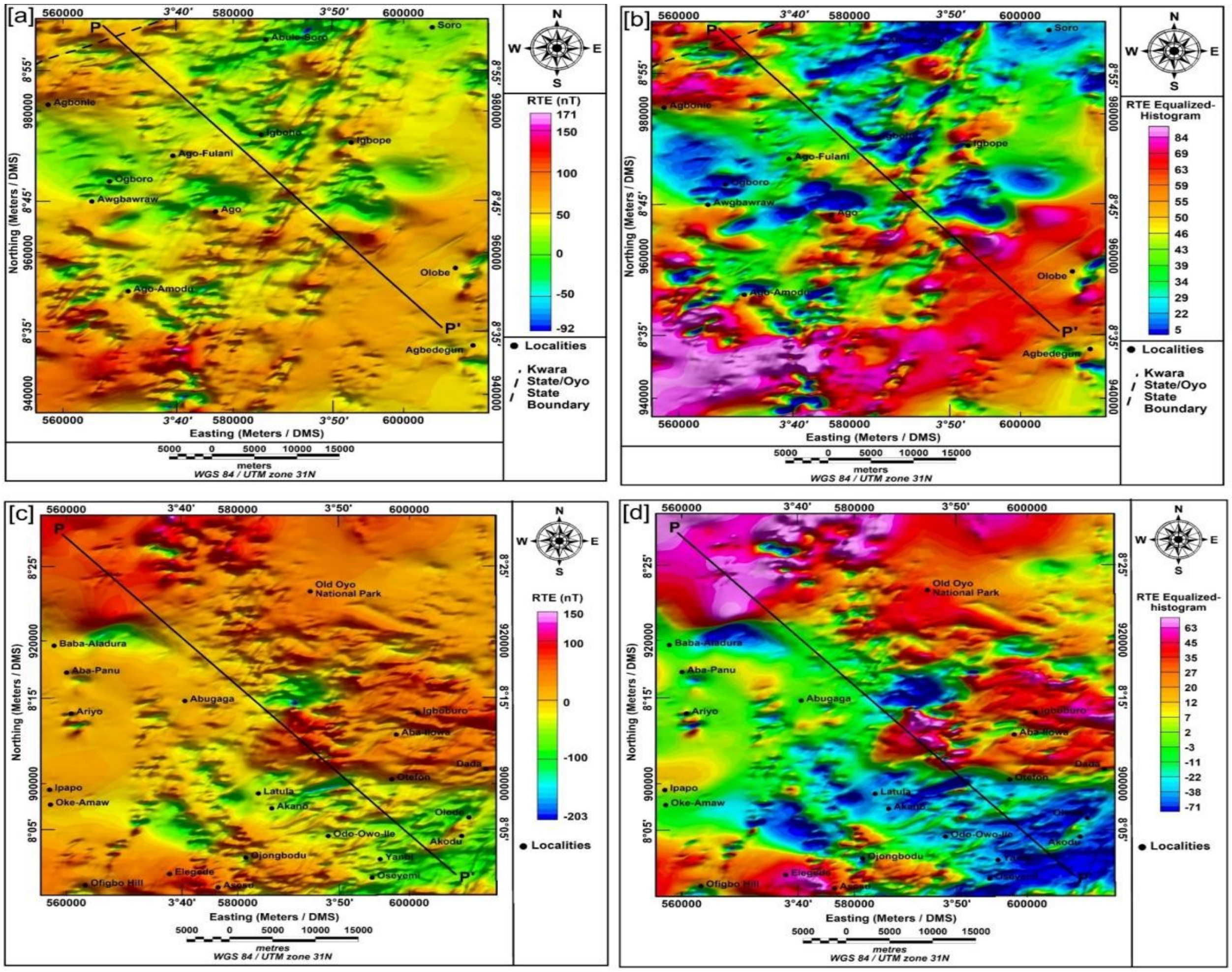

Figure 4: Reduced-to-equator maps of the study area, (a) Igboho linear color, (b) Igboho equalized histogram color, (c) Lechilaku linear color, (d) Lechilaku equalized histogram color. Line PP' indicates the location and orientation of the Regional Residual separation profile.

3.3. The residual magnetic field (RSF)

The RSF aeromagnetic data of the study area obtained after removing the regional-magnetic field (RGF) data from the denoised reduced-to-equator (RTE) data, are presented in Figure 5, with magnetic anomalies characterized by short wavelength and high frequency manifesting as more discretized aeromagnetic anomalies compared to Figures 3 and 4 of the study area.

The RSF aeromagnetic intensity value of Igboho ranges from -147 nT to 87 nT (Figure 5a), while the Lechilaku value ranges from -182 nT to 120 nT (Figure 5c), using the linear color method. However, the maps using the histogram equalization color method (Figures 5b and d) amplified the very little or non-obvious contrast in magnetic intensity values in Figures 5a and c to become noticeable, with those values ranging from about -27 to about 16 for Igboho (Figure 5b), while from about -36 to about 24 for the Lechilaku (Figure 5d). The amplified magnetic intensity contrast by histogram equalization depicts three distinct zones of magnetic intensity in the study area – the high magnetic intensity (red/pink color zone) dominated in the study area (Figures 5b and d), the intermediate (green color zone), and the low magnetic intensity zone (blue color). The observable general trends of magnetic anomalies on the RSF using Figures 5b and d are approximately NE-SW and NW-SE, which have been widely identified within the Nigerian basement complex and agree with observed geological trends on the geological map of the study area (Figure 2) thereby, giving credibility to the RSF aeromagnetic data and its applicability in extracting the quantitative geological information, particularly the fault architecture of the study area.

3.4. Aeromagnetic lineaments analysis

The lineament extraction technique is applied to the residual map to indicate the existence of faults or other tectonic patterns. Figure 6 shows the lineament map classified into major and minor lineaments, indicating possible major and minor fault lines in the study area. The minor lineaments to an appreciable extent form a clustering and align along the major lineaments, indicating possible

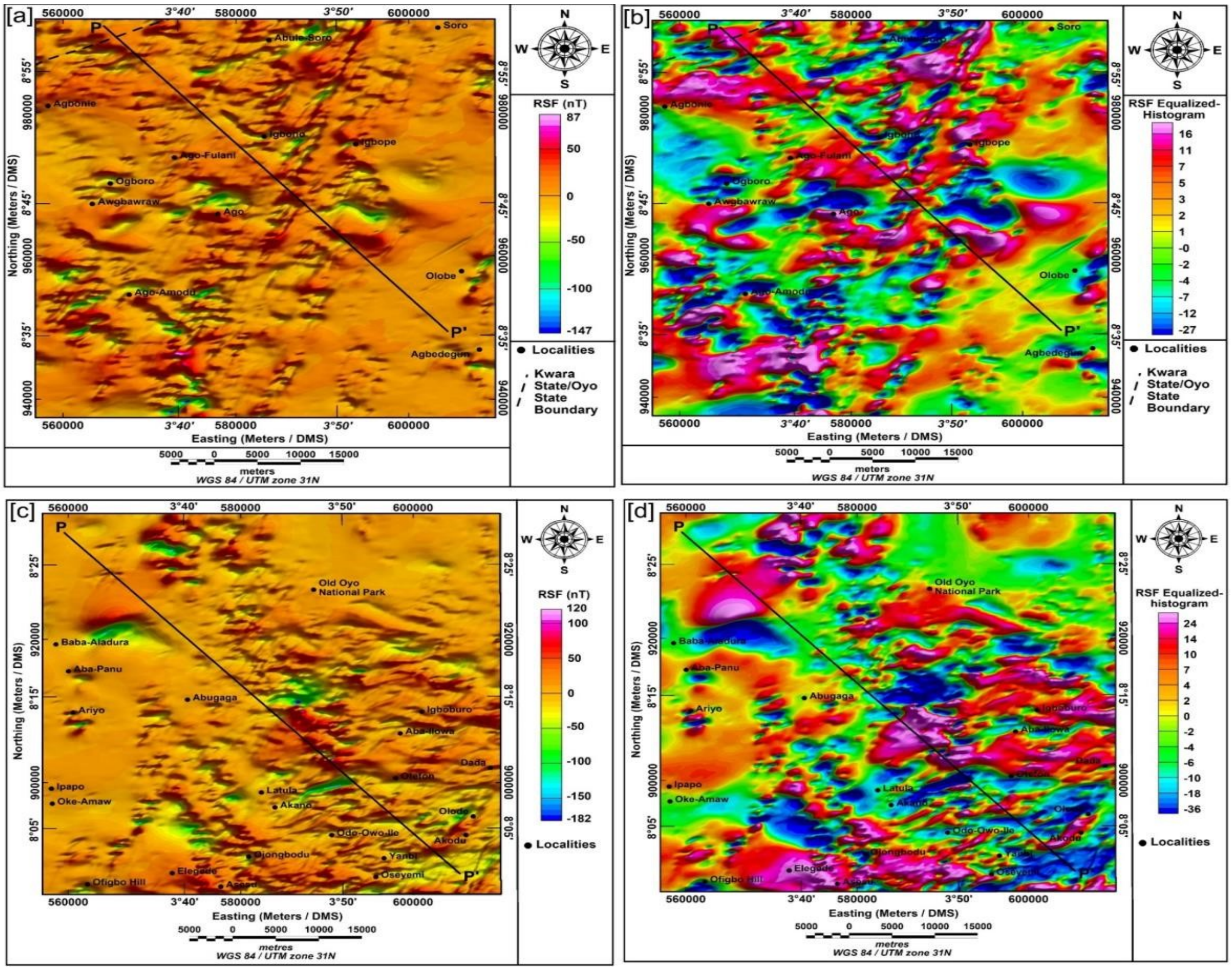

Figure 5: Residual magnetic Field of the Study Area, (a) Igboho linear color, (b) Igboho equalized histogram color, (c) Lechilaku linear color, (d) Lechilaku equalized histogram color. Line PP' indicates the location and orientation of the regional residual separation profile.

subsets and ripple effects of the major aeromagnetic lineaments mapped in the study area. In addition, some of the major lineaments are considerably traceable across the Igboho and Lechilaku (Figures 6a-f), indicating that the major aeromagnetic lineaments are continuous and prominent within the basement rocks of the study area. They are possibly produced by the regional historic orogenic movements that affected the Nigerian basement complex. The superimposition of the lineaments map on the residual maps of the study area (Figures 6b, c, e, and f) shows that the major aeromagnetic lineaments coincide with the perturbations in the local crustal aeromagnetic field of the study area.

The results of the trend and frequency analysis of major and minor lineaments are presented as rose diagrams and lineament density maps, respectively (Figure 7). The rose diagrams (Figures 7a and c) indicate that the prominent trend of the overall aeromagnetic lineaments is ENE-WSW, followed by the ESE-WNW, NE-SW, NNE-SSW, NNW-SSE, and NW-SE. These aeromagnetic lineaments trends indicate that the structural and tectonic framework of the basement in the study area is complex [20]. The ENE-WSW, WNW-ESE, NNW-SSE and NNE-SSW subsurface aeromagnetic lineament trends are regarded as associates of the major NE-SW and NW-SE ancient zones of lineaments in the Nigerian basement complex, and they are supposedly superimposed on a dominant N-S lineament trend [19, 20].

The aeromagnetic lineaments density maps of the study area are presented in Figures 7b and d, indicating the maximum aeromagnetic lineaments density in the study area as 3.4 km/km^2. The dominant lineaments density in the study area is within the range of 0.5 km/km^2 to 1.5 km/km^2 indicated by the green color zone (Figures 7b and d), while the densely populate lineaments zone has density values in the range of 1.5 km/km^2 to 3.4 km/km^2 indicated by the red/pink color zone (Figures 7b and d), and the aeromagnetic lineaments density zone, indicated by blue color is prone to uncontrollable edge effects in the computation of the lineaments density of the study area.

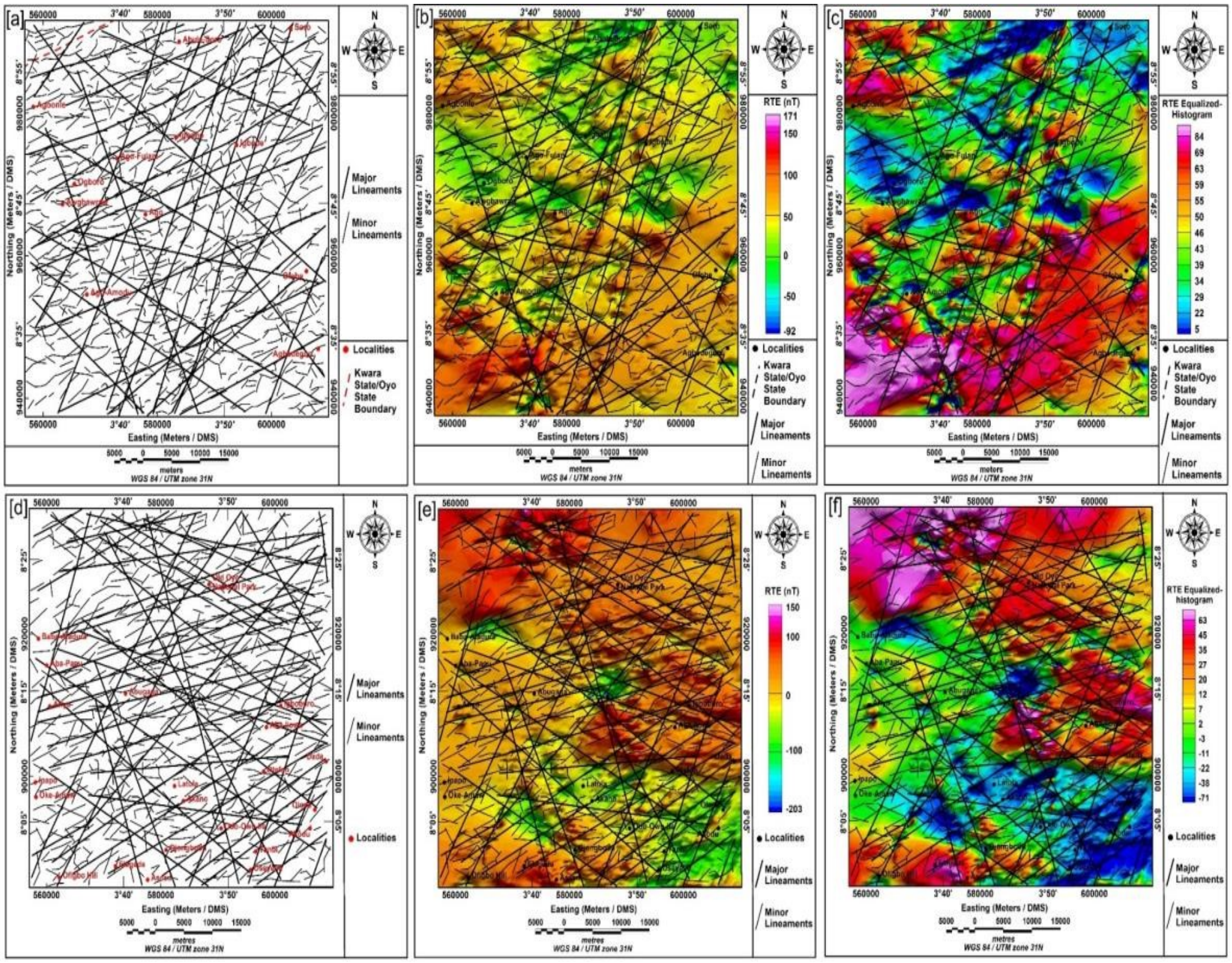

Figure 6: Subsurface aeromagnetic lineaments maps of the study area (a) Igboho lineaments, (b) Igboho lineaments superimposed on its linear color residual map, (c) Igboho lineaments superimposed on its equalized histogram color residual map, (d) Lechilaku lineaments, (e) Lechilaku lineaments superimposed on its linear color residual map, (f) Igboho lineaments superimposed on its equalized histogram color residual map.

Table 1: Summary of the 3D Euler deconvolution depth in the study area.

S/N	Euler Depth Class	Depth Range (m)	Dominance (%)
1.	Shallow (D_1)	3 – 600	Over 90% (high)
2.	Mid (D_2)	600 – 1800	Less than 10% (moderate)
3.	Deep (D_3)	1800 – 3423	Less than 2% (low)

3.5. Total horizontal derivatives (THD)

The results of the total horizontal derivative (THD) map of the study area were presented in the form of linear color and histogram equalization color methods (Figures 8a-d). These maps are characterized with positive anomalies with values ranging from 0-0.80 nT/m, consisting of Igboho anomalies ranging from 0-0.44 nT/m and Lechilaku anomalies ranging between 0 and 0.80 nT/m. The result also depicts three distinct zones with high amplitude zone (red/pink color), intermediate (green color) and low amplitude zone (blue color). The peak amplitudes present in the high amplitude zone have a high magnetic susceptibility contrast and are indicative of the edge locations of aeromagnetic lineaments, which are most likely the faults within the crystalline basement rocks, parallel to the geological boundaries of the study area.

3.6. 3D Euler deconvolution

The resulting 3D Euler deconvolution solutions have been used to evaluate the characteristics of subsurface structures and depth locations of faults, lineaments, and other geologic contacts. It shows considerable and admissible clustering of solutions. But the

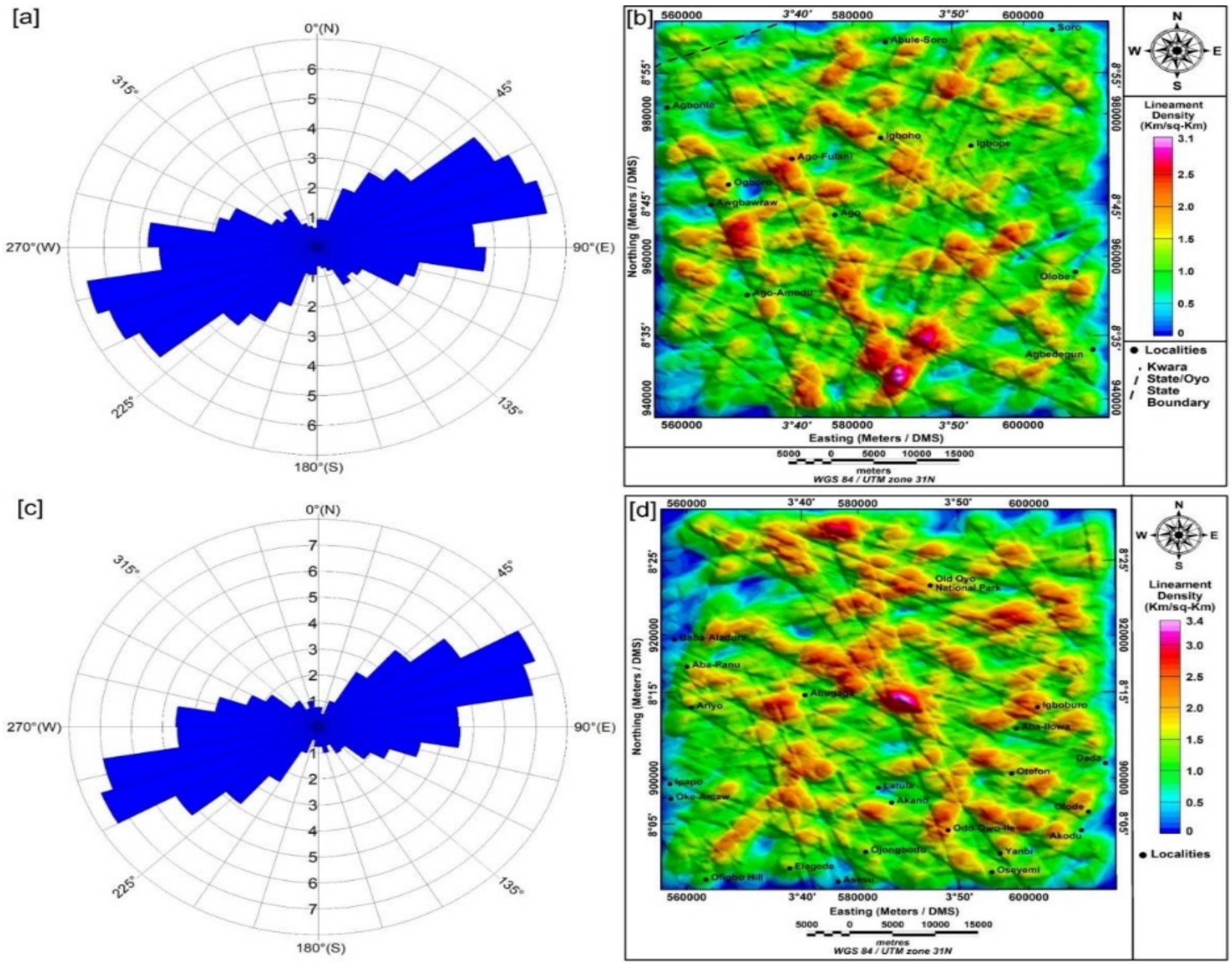

Figure 7: Analysis of mapped aeromagnetic lineaments in the study area (a) Rose diagram of the trend analysis of Igboho data, (b) aeromagnetic lineaments density map of Igboho data, (c) Rose diagram of the trend analysis of Lechilaku data, (d) aeromagnetic lineaments density map of Lechilaku data.

Table 2: Summary of the SPI depth in the study area.

S/N	SPI Depth Class	Depth Range (m)	Dominance (%)
1.	Shallow (D_1)	92-600	Over 90% (high)
2.	Mid (D_2)	600-1800	Less than 10% (moderate)
3.	Deep (D_3)	1800-3213	Less than 2% (low)

Table 3: Summary of the SPI depth in the study area.

Segments	Depth (km)		
	Igboho	Lechilaku	Average
Shallow (Z_1)	0.2	0.2	0.20
Mid (Z_2)	0.4	0.3	0.35
Deep (Z_3)	1.1	1.0	1.05

objective of this is mapping possible tectonic features like faults, geologic contacts, and lineaments. The 3D Euler deconvolution solutions for structural index, $\eta = 1.0$ (Figures 9b and d), are therefore admitted as the correct choice of structural index value in practice [21, 22] for the aeromagnetic data of the study area and were adopted for 3D interpretation (Figure 9b and d) of location, depth, and trend of aeromagnetic lineaments. They show very little diffused solutions compared to figures 9e-h.

The basement depth of geologic structures associated with fault lines is between the range of 3 m and 3423 m, representing the minimum depth (a shallow magnetic source depth that is typical of a basement complex terrain) and maximum depth, respectively.

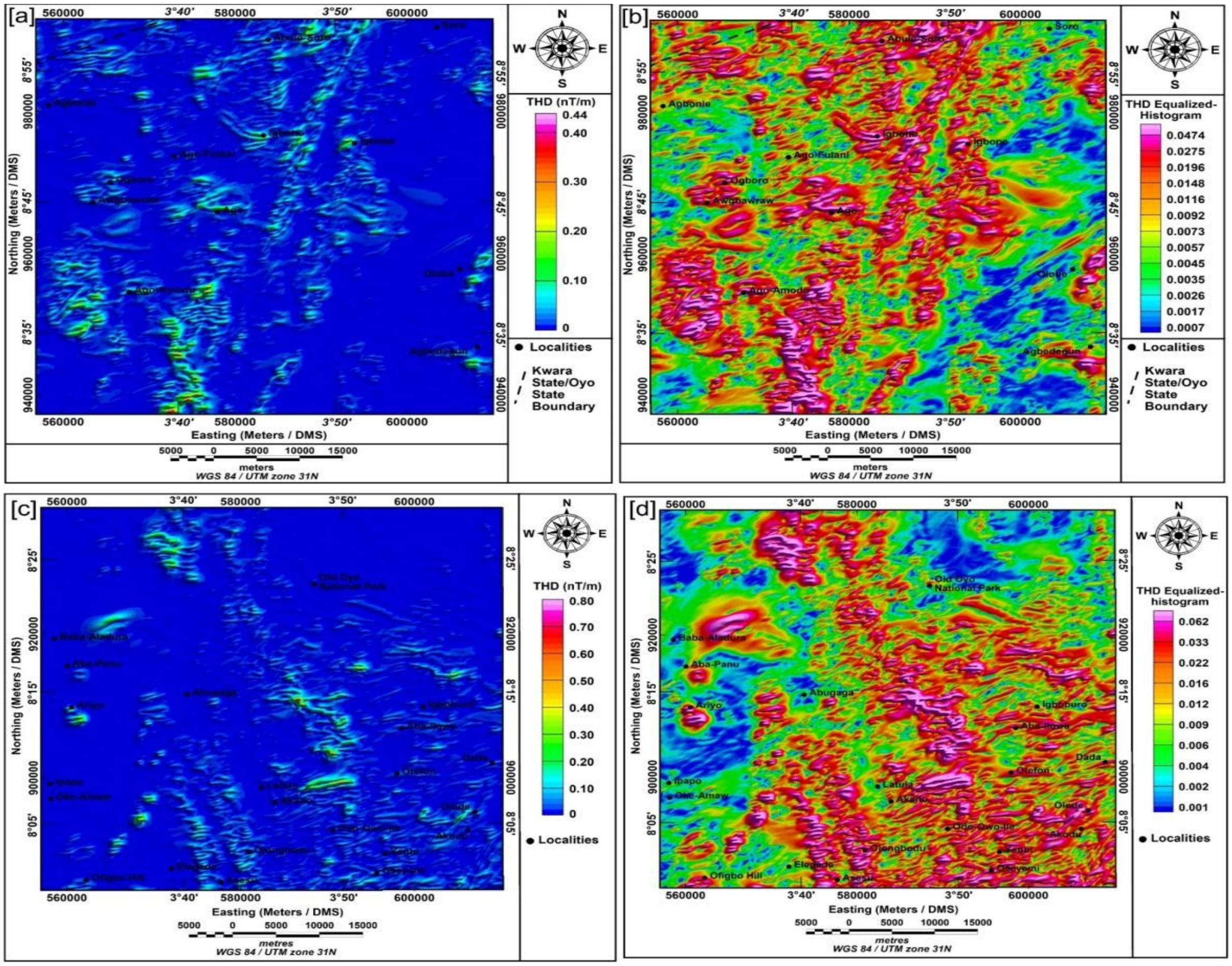

Figure 8: Total horizontal derivative (THD) maps using both linear (L) and equalized-histogram (H) color methods (a) Igboho sheet-L, (b) Igboho sheet-H, (c) Lechilaku sheet-L, (d) Lechilaku sheet-H.

The Euler map of Igboho (Figure 9b) suggests a depth range of 24 m to 3072 m for the northern part of the study area, and the Lechilaku (Figure 9d) suggests a depth range of 24 m to 3072 m for the southern part. The dominant 3D Euler deconvolution depths to basement lineaments of the study area are within the range of 3 m to 600 m (D_1), followed by the range of 600 m to 1800 m (D_2), and the depth range of 1800 m to 3423 m (D_3) is very little in the study area (Table 1).

3.7. Source parameter imaging (SPI)

Figure 10 represents the result of SPI derived from residual magnetic data for determination of depth to magnetic basement rocks, presented on color shaded relief maps of both linear and equalized histogram color methods. The depth to magnetic sources ranges from 92-3213 km (Table 2). From the linear color map presentation, it is apparent that over 90% of the study area is predominantly occupied with the magnetic sources having depth within the range of 92 m to 600 m, as indicated by the blue color zone, and agrees with the predominant 3D Euler deconvolution depth (D_1) of magnetic sources in the study area. The second dominant SPI depth to magnetic sources of the study area is in the range of 600 m to 1.8 km indicated by the green color zone and agrees with the second dominant 3D Euler deconvolution depth (D_2) to magnetic sources in the study area. The last dominant SPI depth is in the range from $\approx$ 1.8 km to $\approx$ 3.2 km indicated by the red/pink color zone on the SPI depth linear color maps of the study area and agrees with the last dominant 3D Euler deconvolution depth (D_3) to magnetic sources in the study area.

3.8. Radially averaged power spectrum

The results of the 2D radially averaged power spectrum analysis carried out on the residual aeromagnetic data of the study area are presented in Figure 11, including the Igboho power spectrum plot (Figure 11a) of the northern part and the Lechilaku power spectrum plot (Figure 11b) of the southern part of the study area. As expected of a typical 2D radially averaged power spectrum plot, of an aeromagnetic data, the radially averaged power spectrum plots of the study area exemplify reduction in energy with increasing

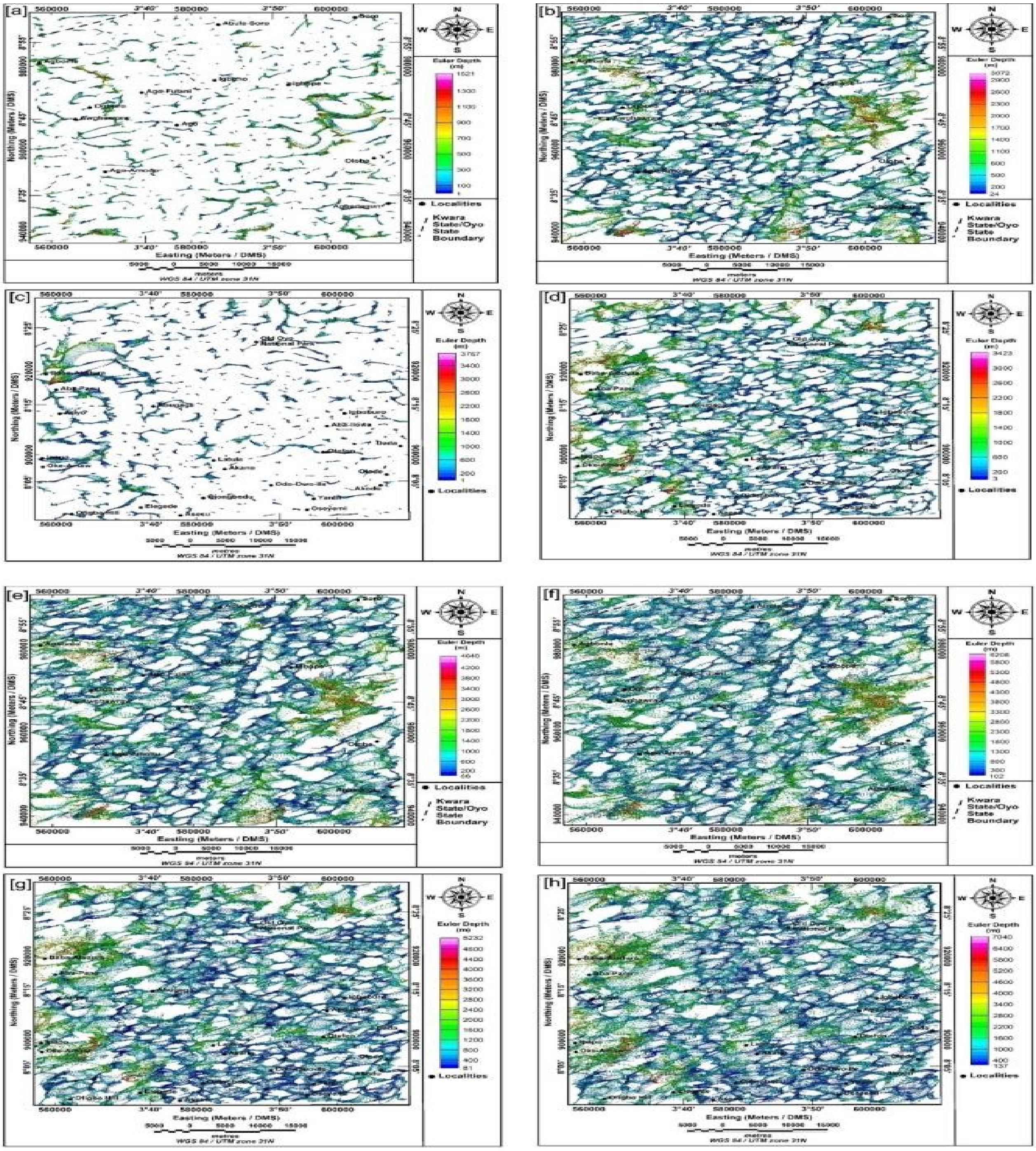

Figure 9: Maps of 3D Euler deconvolution solutions of the study area (a) Igboho sheet structural index, η = 0, (b) Igboho sheet structural index, η = 1.0, (c) Lechilaku sheet structural index, η = 0, (d) Lechilaku sheet structural index, η = 1.0, (e) Igboho sheet structural index, η = 2, (f) Igboho sheet structural index, η = 3, (g) Lechilaku sheet structural index, η = 2, (h) Lechilaku sheet structural index, η = 3.

wavenumber [23]. Three distinct segments are identified on each of the spectral plots and a red linear trend line was fitted to each of the segments. This is to determine the average slope of each segment for the estimation of the depth to magnetic sources represented by each segment. The estimated spectral depth to magnetic source populations within the study area is summarized in Table 3. It is noteworthy that the spectral depths obtained for magnetic source populations in the study area (Table 3) fall within the predominant and moderate depth range of magnetic sources obtained from the 3D Euler and SPI technique applied to the residual aeromagnetic data.

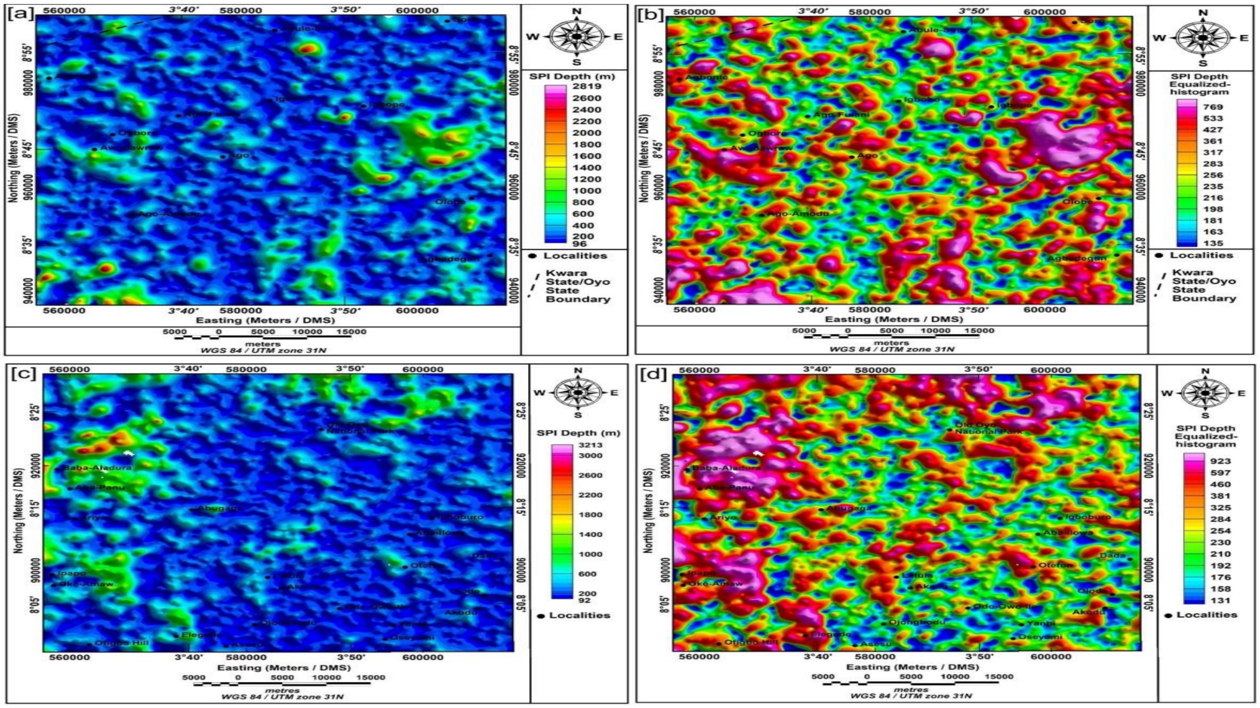

Figure 10: Source parameter imaging (SPI) maps of the study area presented using both linear (L) and equalized-histogram (H) color methods (a) Igboho sheet-L, (b) Igboho sheet-H, (c) Lechilaku sheet-L, (d) Lechilaku sheet-H.

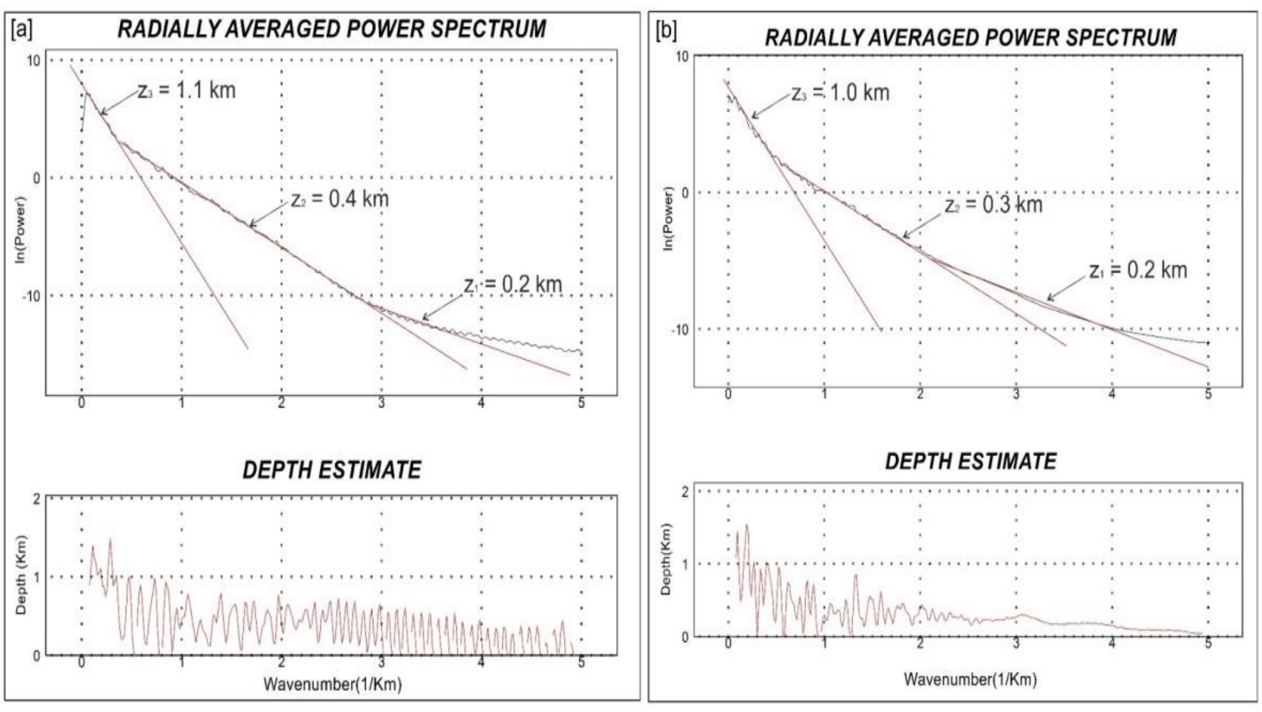

Figure 11: Radially averaged power spectrum plot of the spectral analysis of the aeromagnetic data of the study area (a) Igboho sheet 200, (b) Lechilaku sheet 221.

4. Conclusion

The geoscientist was initially ignoring research in the area of earthquake occurrence simply because Nigeria as a country is believed to be tectonically stable, thereby prompted very little research in the area of earthquake before 1984 occurrence. However, events between 1990 and 2000 have triggered the need to provide adequate earthquake information in the study area. Moreover, the results of qualitative and quantitative interpretation of the study area presented using the histogram equalization color method amplified very little to non-obvious contrast in the linear color method to become noticeable. The results also show a positive correlation with the geological structure of the study area; low magnetic anomalies depict subsurface deformation of crystalline basement rocks. The 3D Euler deconvolution for structural index = 1 was admitted for correct choice of SI value in practice showing large clusters in the study area, which also depicts geological structures associating with fault lines. The result of depth to magnetic basement from 3D Euler deconvolution and SPI techniques shows over 90% dominance of shallow depth in the study area, with depth values ranging from 3-600 m. This depicts a shallow depth of magnetic basement as a result of the subsurface intrusion causing the faulting system of subsurface to become weak zones through which earth tremors can occur.

4.1. Recommendation

Enhanced Seismic Monitoring: The study reveals shallow basement structures and faulting systems in the Saki-East area, suggesting weak zones prone to tremors. Therefore, it is recommended to establish or enhance seismic monitoring networks in the region to detect early signs of earth tremors and provide timely warnings for nearby communities.

Further Geophysical Investigations: The correlation between magnetic anomalies and subsurface deformation highlights the need for more comprehensive geophysical surveys. Expanding the scope of studies, including gravimetric and resistivity measurements, could provide a more detailed understanding of the structural framework and further confirm areas of potential seismic hazards.

Infrastructure Risk Assessment: Since the research shows that shallow basement depths are linked to the weakening of fault systems, authorities should assess the risk posed to existing infrastructure in the area. This includes evaluating the potential impact of tremors on buildings, roads, and other critical structures, and recommending reinforcement where necessary.

Geotechnical Zoning and Land Use Planning: The identification of major and minor lineaments implies fault zones and areas of weakness in the bedrock. Local governments and urban planners should incorporate this information into zoning policies to avoid placing critical infrastructure in seismically vulnerable zones. Areas near major lineaments could be designated for lower-risk land uses.

Data availability

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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