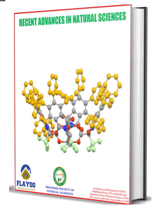
Published by Nigerian Society of Physical Sciences. **Hosted by** FLAYOO Publishing House LTD

Recent Advances in Natural Sciences

Journal Homepage: https://flayoophl.com/journals/index.php/rans



Lithological and structural mapping of parts of southwestern Nigeria using aeromagnetic data

Emmanuel Ike[a,*], Adetola Sunday Oniku[a], Sabastine Chinedu Ezike [a], Rodney Ewusi-Wilson[b]

[a]*Department of Physics, Faculty of Physical Sciences, Modibbo Adama University, Yola, Nigeria*
[b]*Department of Civil Engineering, School of Engineering, Cape Coast Technical University, Cape Coast, Ghana*

ARTICLE INFO

Article history:
Received: 10 November 2023
Received in revised form: 17 December 2023
Accepted: 18 December 2023
Available online: 20 January 2024

Keywords: Aeromagnetic data, Vertical derivatives, Horizontal derivatives, Upward continuation, Analytic signal, Lineaments.

DOI:10.61298/rans.2024.2.1.54

ABSTRACT

This study investigates earthquakes in Nigeria since 1933, aiming to discern their precise causes. Focusing on Southwestern Nigeria, it explores underground geological frameworks and hydrothermal alteration zones that may influence seismic energy transmission, groundwater storage, and mineralization. Data optimization involved vertical derivatives, horizontal derivatives, upward continuation, and an analytic signal approach. The study area features sinistral and dextral faults along NE-SW, NW-SE, N-S, and E-W directions. The NE-SW trend, indicative of major lithospheric processes, intersects formations beneath key locations such as Ikogosi warm spring, Ipole-Iloro waterfall, Arinta waterfall, Effon-Alaaye waterfall (all in Ekiti state), and Erin-Ijesha waterfall (Osun State), aligning with granite and adjoining fractures. The quartzite belt in the NE–SW direction forms an aquifer network with substantial storage potential. The NNE-SSW trends correspond to significant lithospheric processes and fractures beneath locations like Ikogosi warm spring, Ipole-Iloro waterfall, Arinta waterfall, Effon-Alaaye waterfall (all in Ekiti state), and Erin-Ijesha waterfall (Osun State). These trends relate to the Ifewara-Kalangai fault, while NW-SE depicts the separation of the South American and African plates. Overlapping NW-SE and NE-SW lineaments suggest fractures from similar tectonic events, possibly the Pan African orogeny. Intersection points are plausible zones for groundwater, geothermal resources, and mineralized targets, evidenced by small-scale mining activities. Fault lines act as channels for seismic energy transmission, leading to earth tremors, and serve as guides for solid mineral prospecting and geothermal exploration. The study enriches knowledge about future earthquake occurrences, aiding hazard prevention measures.

1. INTRODUCTION

Natural disasters are becoming economically more significant on a global scale as well as on localized level. The concerns about natural disasters, disaster mitigation, and avoidance have received attention due to the expansion of cities especially in vulnerable areas coupled with the anxiety associated with the occurrence of earthquakes like the damage of structures, fire breakouts, and loss of life [1]. A tremor is a relatively minor, short-lived or involuntary seismic movement of the earth's crust, with

*Corresponding author: Tel.: +234-806-2356-335;
e-mail: emmanuelike@mau.edu.ng (Emmanuel Ike)

magnitude measuring from 1 – 4.5. They are notwithstanding caused by the same forces that produce earthquakes of low or moderate intensity. However, an earthquake is a sudden vibration of the terrestrial surface with the release of elastic energy.

In the last few decades, scientists have been upbeat about the possibility of earthquake predictions in Nigeria. Results of several investigations suggests that the incident of substantial earthquakes event was sometimes heralded by anomalous behavior of animals and variations in certain phenomena such as changes in groundwater level, changes in magnetic and electric field intensities, and small changes in the topography around the causative earthquake fault [1]. Probabilistic forecasting of earthquakes both in short and long term is well established [2–4]. However, to warn vulnerable communities of impending floods, earthquakes, and related coastal disasters, an advance warning system is essential. The early warning system will ensure readiness for national emergency rescue, poverty reduction and socioeconomic development projects.

Considering its distance from the world's major earthquake zones, coupled with the fact that the nearest active plate boundary is in the far-off Mid-Atlantic Ridge, which has been recognized as a stable continental region, the Nigerian land mass is hence unlikely to be impacted by geogenic earthquakes. There have been isolated instances of earth tremors observed across the nation (Figure 1), interestingly Southwestern Nigeria registers most record of earthquake activity, the highest number of events with intermediate strength ranging between 4.0 and 4.5 [1, 5, 6]. The earliest documented tremor in Nigeria in 1933 was in Warri (Delta state) and Ohafia (Abia State), after which similar event occurred in Lagos and its environs in 1939 [7], another quake was reported around Ohafia in 1961, while the most recent was felt within Abia State, Nigeria in 2020 [8].

According to Ajakaiye, *et al.* [9], the most severe episode of tremors struck around Ijebu Ode (1984, 1963, 1990, 2000), Lagos (1939, 1963), Ibadan (1939, 1963, 1984, 1990, 2000), and Ile-Ife (1939, 1963), Shagamu (1984), Abeokuta (1984, 2000), Okitipupa (1997), Akure (2000), Shagamu (2000), Oyo (2000) [1, 9]. In summary, between 1933 and 2015 Nigeria experienced 31 Earth tremors [10, 11], four (4) of which occurred in 1984 and 2000 while three (3) occurred in 1987. About ten (10) tectonic events were observed in 2016, two (2) in 2018 and 2019 (Abuja), one (1) in 2020 (Abia state), totaling 44 seismic activities [8]. According to the modified Mercalli Intensity Scale, the seismic episodes was between III to VI.

Only tremors at Ijebu Ode in 1984, Ibadan in 1990, Dan Gulbi in 1994, and Jushi-Kwari in 2000 were recorded with seismic instruments, whereas only the epicenters of the 1984 and 2000 events could be identified. These events had local magnitudes, surface wave magnitudes and body wave magnitudes in the range of 3.7 to 4.2, 3.7 to 3.9 and 4.3 to 4.5 respectively [1]. When the rest seismic activities happened, there were few or no station to record them; hence earthquake history were documented from oral history from the aborigines of the affected area, personal and newspaper articles written between 1933 - 2011. Presently, Nigeria has seismographic network with four operational stations and plans are underway to add more to the network [5]. These aforementioned records in Nigeria's geological history cast doubt on the conventional wisdom holding that the country is seismically safe.

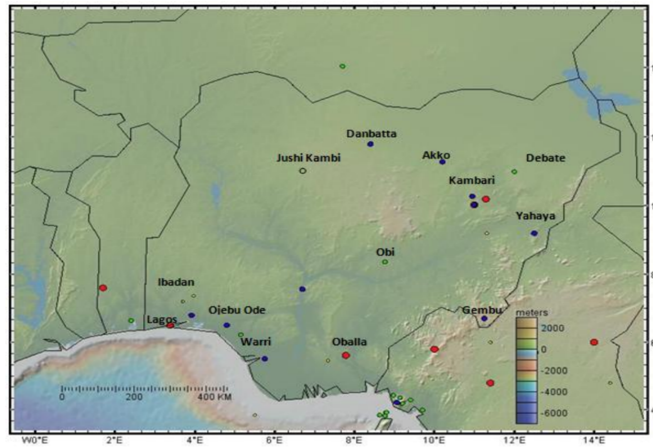


Figure 1. Map of Nigeria showing epicenters of earthquakes and other seismic events from adjacent countries of Cameroon and Benin Republic, both historical events and some instrumentally recorded ones. The magnitudes range between 3 to 4 (yellow solid dots); 4 to 5 (Green solid dots); 5 to 6 (Red solid dots); and blue solid dots represent historical tremors with unknown magnitude [5].

These seismicity is likely due to geological and/or geotechnical stress pattern formed by the interplay between the West African Craton and the Congo Craton [7], events of magmatic intrusions and other lithospheric events that resulted in inhomogeneities and weak spots in the crust. Two theories were put forth as the causes of the seismic activity in the nation. The first postulated the Yola-Dambata and Akka-Jushi fault systems as well as the Warri-Ijebu Remo systems [6], which largely trend along NW – SE were identified using the spatial distribution of earth tremors. The second claim is that the activities may well have been triggered by tremors that occurred in the inshore part of the Northeast – Southwest fractures zones originating from the "Sea of Atlas" and traversing the Southwestern Nigeria, which is related to the Ifewara-Zungeru fault network [7, 9, 10, 12]. This Atlantic transform faults consists of the St Paul, Romanche, Charcot and Chain fractures zones.

The above discourse shows that there are distinct earthquake belts in Nigeria and it is impossible to attribute the same cause to earthquakes that occur in various regions of Nigeria. The focus of the present study is the delineation and characterization of underground geologic frameworks and hydrothermal alteration zones that could harbor mineralization within Southwestern part of Nigeria majorly in terms of lineaments using aeromagnetic data. Also, we intend to enrich the existing knowledge about possibility of future earthquake occurrence in Southwestern Nigeria that will assist in hazard prevention and reduction. These will be achieved by generating maps showing lineament in the study area. The data processing techniques employed are the vertical derivatives, horizontal derivatives, upward continuation, and analytic signal approach.

2. GEOLOGY OF THE STUDY AREA

The research area is between latitudes 6°23′ and 7°38′ and longitudes 3°53′ and 5°8′ and underneath we have the Precambrian basement complex structure which is the principal geologic unit

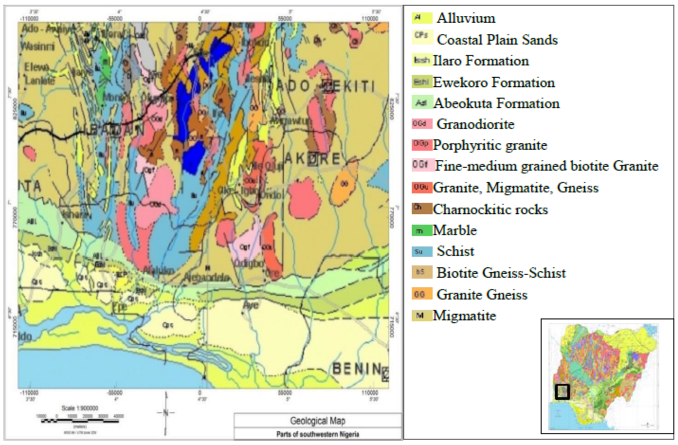


Figure 2. Geological Map of the Study Area (Geological Survey of Nigeria, 2015) [5].

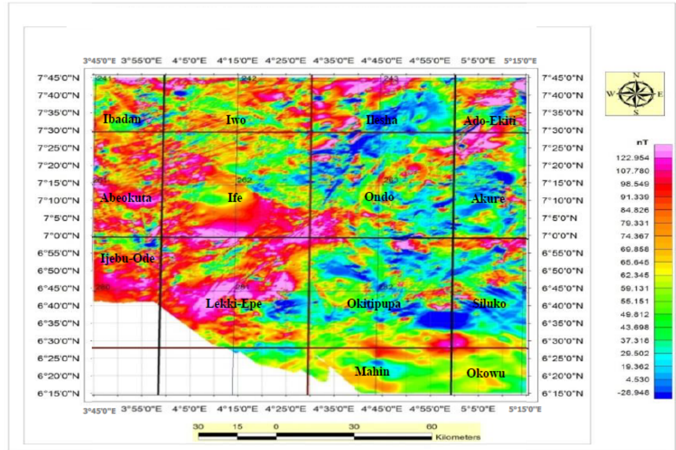


Figure 3. Total Magnetic Field Intensity Map of the Study Area (Add 33,000 nT to the legend value to obtain the actual value).

covering about 90% of the entire Southwestern Nigeria, excluding the southern region; around Lagos State and parts of Ondo state which are coastal in nature and forms part of the sedimentary basins emanating from the Bida basin [7]. The Precambrian basement complex (Figure 2) is a component of the Pan African orogenic belt situated between the west African/Congo Cratons and towards the South of Tuareg Shields; occupying the reactivated region of the Pan-African orogeny brought about by the collisions of plates belonging to the (passive) continental margin of the west African Craton and the (active) Margin of the Pharusian continent.

Geologically, the basement complex is derived primarily from mountain-building cycles of deformation, metamorphism and remobilization. These cycles are marked by extensive deformation and isoclinal folding, which led to regional metamorphism, and large-scale migmatization, granitization and gneissification [13]. The final stages of the deformation are defined by features such as granite placement, granodiorites, and contact metamorphism, leading to faults and fractures [14].

3. MATERIALS AND METHODS

3.1. MATERIALS

The aeromagnetic data was acquired by Fugro Airborne Survey Services using airborne magnetometer (3x ScintrexCS2 Cesium Vapour), on a map scale of 1: 100000 series (Figure 3). The survey was carried out along Northwest - Southeast Flight Lines while the Tie Line was along the Northeast - Southwest direction with 500 m Flight Line Spacing. The Tie Line Spacing was 5000 m, Flight Line Trend of 135 degrees, Tie Line Trend of 225 degrees, Sensor Mean Terrain Clearance of 80 m, at an elevation of 100 m and magnetic data recording interval of 0.05 seconds. For this study,fourteen (14) digital map sheets covering Ibadan (Sheet No. 241), Iwo (Sheet No. 242), Ilesha (Sheet No. 243), Ado-Ekiti (Sheet No. 244), Abeokuta (Sheet No. 261), Ife (Sheet No. 262), Ondo (Sheet No. 263), Akure (Sheet No. 264), Ijebu-Ode (Sheet No. 280), Lekki-Epe (Sheet No. 281), Okitipupa (Sheet No. 282), Siluko (Sheet No. 283), Mahin (Sheet No. 296) and Okowu (Sheet No. 297) were used. Data from the Aeromagnetic Anomaly Map were extracted using GEOSOFT Oasis Montaj Software as the Maps are in GEOSOFT Grid File Format, the Surfer Software Version 11.0 was used in plotting all the contour maps, while the diurnal magnetic variations and the geomagnetic gradient were eliminated using a reference field as defined by Alken, *et al.* [15].

3.2. METHODS

This section involves the use of filters on the aeromagnetic data that will enhance the presentation and interpretation of results. Considering the nature of the magnetic field trends in the survey area, the Oasis Montaj Software was used to separate the regional anomaly from the data by fitting a plane polynomial surface. In the light of the absence of complex geology in our study area, it becomes appropriate to adopt a two dimensional first-degree polynomial surface in the regional field. The data processing techniques adopted in this study have been given in previous literatures [16–21], and they are Analytic Signal Approach, Upward Continuation, Horizontal Derivative, and Vertical Derivatives.

3.2.1. Analytic signal approach

Analysis of observed magnetic anomalies is usually convoluted due to their displacement parallel to the plane of the horizon compared to their sources. This tilt is because of the fact that largely, the directions of the geomagnetic field and induced magnetization are not vertical, and re-aligning these anomalies via reduction to the pole process is complex, especially in a case where we have low magnetization inclination. The analytic signal is very good at identifying edges of remanently magnetized bodies and aligning anomalies over their source bodies in locations of low magnetic latitude [22]. The amplitude of a 3D analytic signal of the total magnetic field at any location is derived using the expression [19, 22];

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

where F is the magnetic field at points x and y. This processing technique avoids the difficulties that are usually encountered in the reduction to pole process, when the influence of natural remanent magnetization on the source magnetization distribution are not clearly known [19]. Regardless of the magnetization direction, this processing technique is frequently employed in outlining geologic features like contacts and faults.

3.2.2. Upward Continuation

The short frequency anomalies caused by deep density contrast (regional anomalies) is crucial in comprehending large scale structure of the earth's crust as exemplified in major landforms, such as mountain ranges, oceanic ridges, major fault line, and subduction zones [23]. The upward continuation accentuates anomalies due to deep seated causative bodies (regional features), as against anomalies due to shallow seated ones. Such near surface causative bodies include basic intrusions, lava flows, dykes, metamorphic basement rocks, folded sills and magnetite ore bodies. The upward continued field ΔF at higher level (z = -h) is expressed as [23];

$$\Delta F(x,y,-h)=\frac{h}{2\pi}\iint\frac{\Delta F(x,y,0)\partial x\partial y}{\sqrt{(x-x')^2+(y-y')^2+(h)^2}}, \tag{2}$$

where ΔF denotes the Total Field Magnetic Anomaly. $F(x',y',-h)$ represents the Total Field and h is upward continuation height.

3.2.3. Horizontal derivative

The horizontal derivative promotes short wavelength horizontal variations in potential field data, due to faults or boundaries between different geological units. If the magnetic field is F(x,y), then the horizontal derivative [H (x, y)] is expressed as [24];

$$H\ (x,\ y)=\sqrt{\left(\frac{\partial F}{\partial x}\right)^2+\left(\frac{\partial F}{\partial y}\right)^2}. \tag{3}$$

This processing technique earmarks linear features which are associated with fault systems in the study area. These linear characteristics allow for easy fault detection, demonstrating the efficacy of these filters in the interpretation. After tracing the faults on the linear features on maps, they will be correlated with the regional geology.

3.2.4. Vertical derivatives

The vertical derivatives technique promotes very shallow geologic sources, encourages enhanced resolution of closely-spaced sources while it suppresses deep seated geologic sources [21]. To make the effects of shallow geologic sources more pronounced, second, third and higher order vertical derivatives are conducted. However, at or above the second order vertical derivatives, the data becomes noisier than the signal. The nth vertical derivatives (V (ω)) is expressed as [21];

$$V\ (\omega)=\ (2\pi K)^n, \tag{4}$$

where; ω = angular wavenumbers (radians/ground unit) K = wavenumbers (cycles/ground unit) n = order of differentiation

4. RESULT

4.1. ANALYTIC SIGNAL APPROACH

The gradients of the magnetic anomaly are combined to provide the analytic signal or total gradient. Determination of the source characteristics is dependent on analysis of the magnetic anomaly's first derivatives. Figure 4 gives the analytic signal map of this study. The figure reveals that majority of the anomalous expressions trend along SW-NE, NW-SE, N-S and E-W directions.

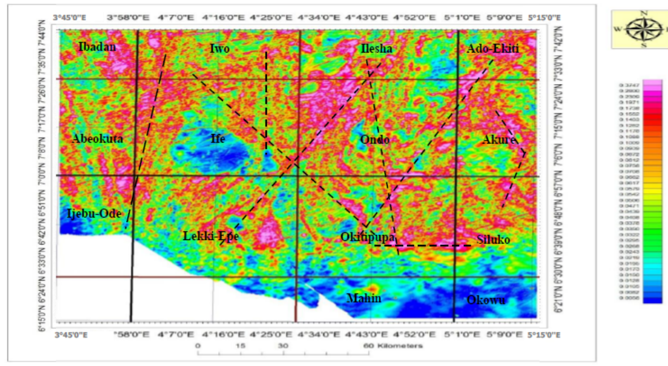


Figure 4. Analytical signal map of the study area showing trends of lineaments.

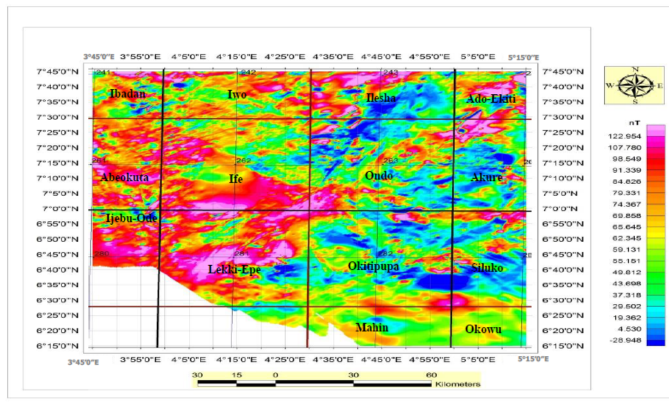


Figure 5. Upward Continuation Map of the Study Area for 100 m (Add 33,000 nT to the legend to obtain the actual value).

4.2. UPWARD CONTINUATION

This data processing technique was implemented on the residual aeromagnetic data above the flight height at 100 m, 500 m, 1000 m, and 2000 m where there is very minimal noise intensity of the second vertical derivative grid, in addition to revealing the basement at these points as respectively displayed by Figures 5, 6, 7 and 8. The upward continuation transformations show how anomaly character changes as observation distance from the magnetic source increases. The 2000 m upward continued map offers a very comprehensive expression and accurately depicts true geology of the study site.

4.3. HORIZONTAL DERIVATIVE

The appropriateness of the horizontal magnetic derivatives in the delineation and characterization of structural features is well documented. Importantly, an abrupt change in the strength of magnetic expression would suggests interface between basement fault. Figure 9 shows the contrasted linear features from the horizontal derivative operation. The zones of continuous minima am-

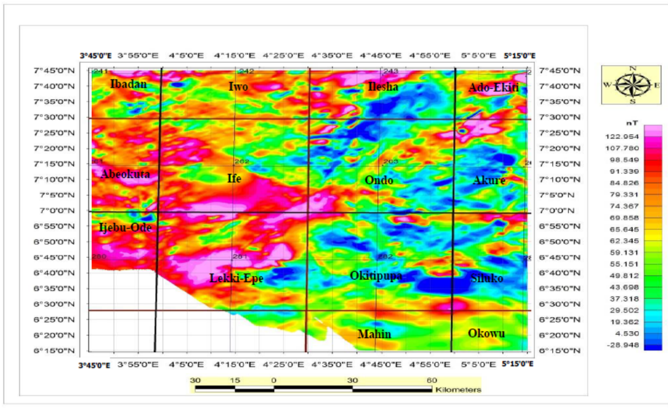


Figure 6. Upward Continuation Map of the Study Area for 500 m (Add 33,000 nT to the legend to obtain the actual value).

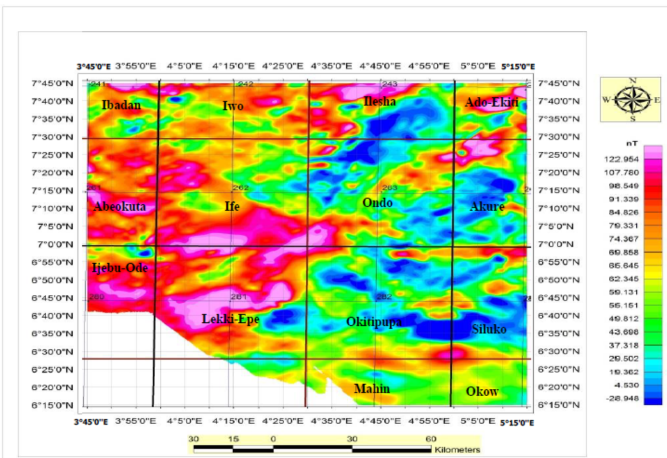


Figure 7. Upward Continuation Map of the Study Area for 1000 m (Add 33,000 nT to the legend to obtain the actual value).

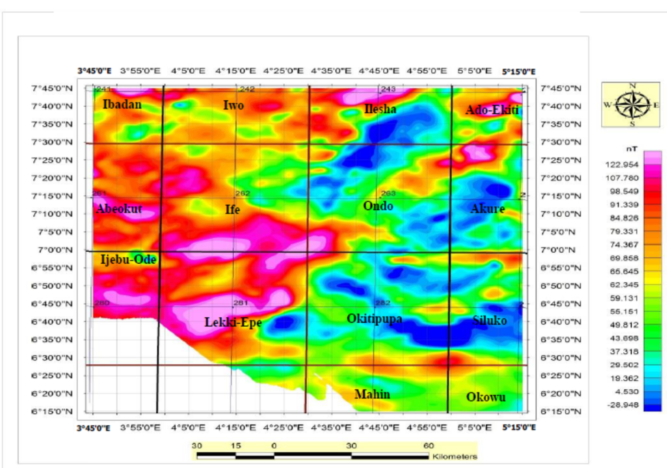


Figure 8. Upward Continuation Map of the Study Area for 2000 m (Add 33,000 nT to the legend to obtain the actual value).

plitude, that is the feebly magnetized regions (continuous minima amplitude) on the horizontal derivative map in Figure 9 are traced along these linear features and marked as lineaments, revealing

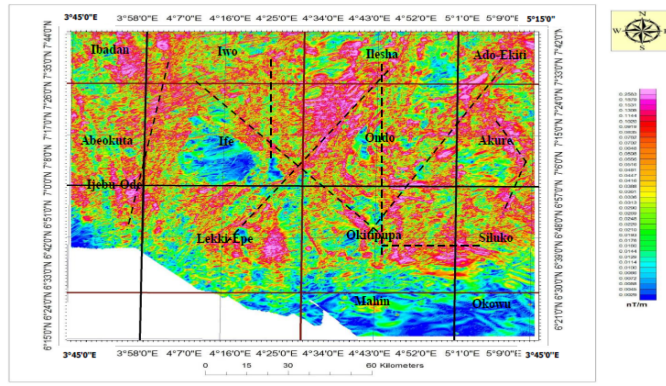


Figure 9. Horizontal Derivative Map of the Study Area showing Trends of Lineaments (Add 33,000 nT to the legend to obtain the actual value).

distortional behavior. These features are then corroborated with the geology of the research area.

4.4. VERTICAL DERIVATIVE

This edge delineating filter is very effective in identifying near surface contacts and lineament, as it enhances short wavelength characters associated with shallow features. Figures 9 and 11 shows the trends observed in our study area. The observed lineaments in the vertical derivative maps confirm those observed in the upward continuation and horizontal derivative maps earlier conducted.

4.5. DISCUSSION

The magnetic anomaly maps show high magnetic field strength at the basement complex and low magnetic field strength at the sedimentary basin. The high magnetic field strength at the basement is probably due to the influence of hematite and magnetite while the low magnetic field intensity is could be as a results of the presence of schist. A closer observation of the analytic signal map (Figure 4), horizontal derivative map (Figure 9), first vertical derivative map (Figure 10) and second vertical derivative map (Figure 11) show that a well dissected trend exists in the study area, structural features trend along Northwest (NW) – Southeast (SE), Northeast (NE) – Southwest (SW), North-northeast (NNE) – South-southwest (SSW) and North (N) – South (S) directions. We deduced a general NE-SW striking trend, which is most likely due to geologic features (fractures/faults) cross cutting the formation(s) underlying the Ikogosi warm spring area (Ikogosi, Ekiti State), Ipole-Iloro waterfall (Ipole-Iloro, Ekiti State), Olumirin/Erin-Ijesha waterfall (Erin-Ijesha, Osun State), Arinta waterfall (Ipole-Iloro, Ekiti State, Ekiti State) and Effon-Alaaye waterfall (Effon-Alaaye, Ekiti state) Also, the Owu waterfall (Owa Kajola, Kwara state), and Soose spring (Odo Soose, Kwara state), which are located just on top of our study area. The quartzite belt stretching in a NE – SW direction for more than a hundred kilometer (the site of the main supply of the warm springs in Ikogosi) is regarded as an aquifer network with a significant storage potential [26]. Since the geophysical and geological features in the study area are structurally controlled (in terms of fractures and/or magmatic intrusions), such region serves as a target for secondary mineralization, so also geothermal reser-

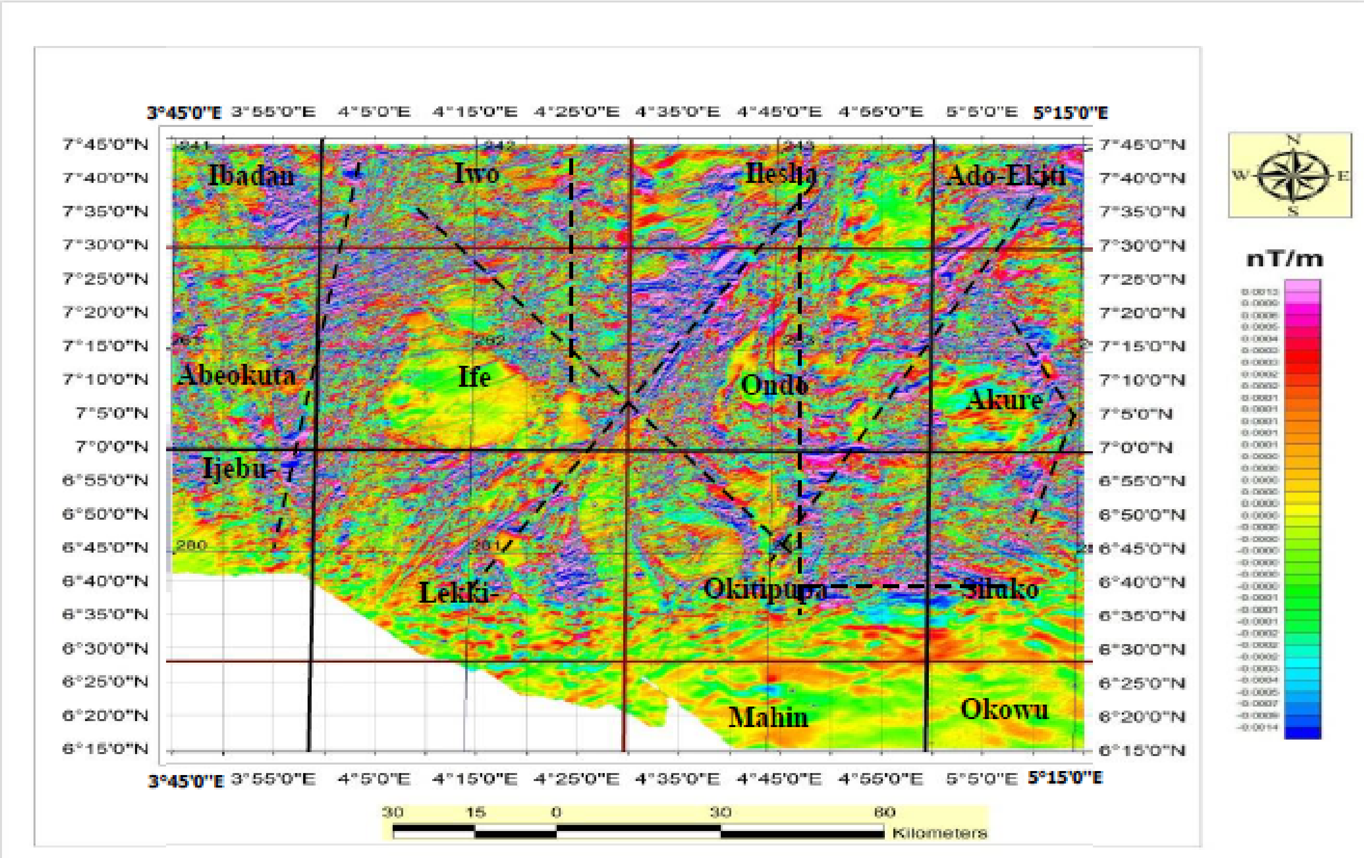


Figure 10. First Vertical Derivative Map of the Study Area showing Trends of Lineaments (Add 33,000 nT to the legend to obtain the actual value).

voir exploration. The overlaps between the NW-SE and NE-SW lineaments (Figures 9-11); implies that these fractures were produced by similar tectonic events. Therefore, it is accepted that the NE-SW set represents fractures attributed to significant movements caused by historic tectonic activity, possibly the Pan African orogeny. In the study area, the locations of lineament intersection are also plausible zones for groundwater prospecting. The identification of these trending features would enable quick recognition of geologic patterns in the region and would also contribute to proper characterization of the geothermal settings therein. The above-mentioned aquifer system explains where majority of the water flow in our research region originates from, and the observations presented above are consistent with the geological make-up of the region. Interestingly, at the bottom of the research area comprising of Lagos State and parts of Ondo state which are coastal in nature are not Precambrian basement complex yet they experienced series of earthquakes/tremors, the seismic events in this region could be as a result of the accumulation of sediments from the ocean. This can be explained as follows, regions where the earth is overburdened with sediments, the plate is usually in distress. These thick sediments can initiate earth movement because a rock mass that already has structural flaws fractures when stress is applied. Once fracture has occurred, movements will continue on such distressed plates. Furthermore, the frequency with which the underground water resources are being exploited may also be responsible for the tremors that were felt in such coastal. This is because myriads of boreholes in Lagos state and parts of Ondo state share the same aquifer which is the Abeokuta rock in Ogun State, meaning that water collected underground literally float the entire region. Given that earthquake swarms connected to concurrent buckling of the lithosphere are usually regarded as the outcome of magma flow beneath the earth's surface in tectonically active regions of the world, we hereby propose that the seismic activities recorded within our study area, the major fault presence (example the dominant Ifewara-Zungeru fault), and the various faults or joints in rock units may be the result of distress created on the plate due to the buildup of sediment and the excessive exploitation of groundwater (especially in the coastal/Southern part of our study are), the magma flow or presence of magmatic intrusions.

5. CONCLUSION

Though Nigeria is believed to be situated on a stable continental crust, however, several earth tremors that have been witnessed between 1933 to 2022 have proved otherwise. In a bid to determine the actual cause of these seismic activities, this study evaluated these events through the interpretation of aeromagnetic data using technics like vertical derivatives, horizontal derivative, upward continuation, and analytic signal approach aimed at delineating the subsurface structures. The magnetic anomaly maps indicate increased magnetic field strength at the basement complex and low magnetic field strength at the sedimentary basin. The

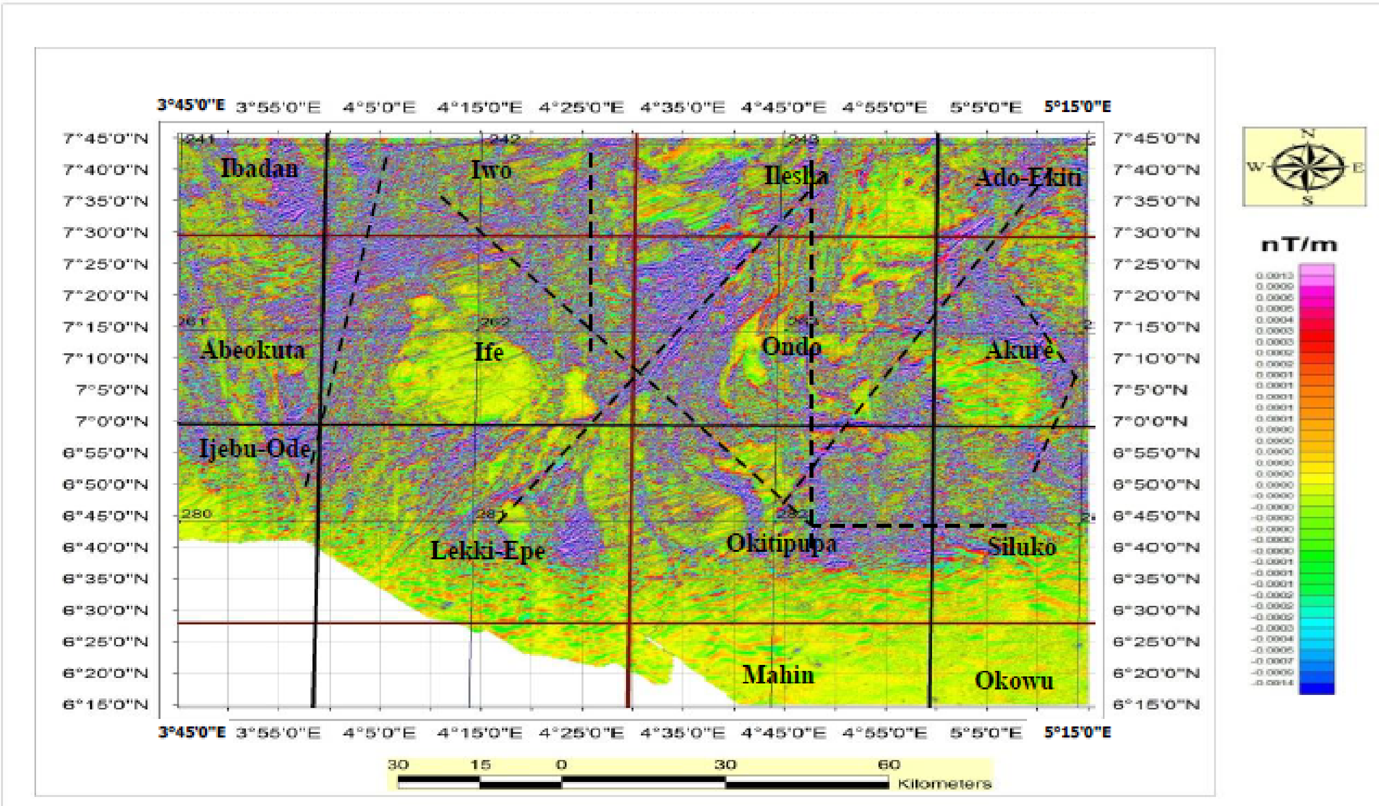


Figure 11. Second Vertical Derivative Map of the Study Area showing Trends of Lineaments (Add 33,000 nT to the legend to obtain the actual value).

high amplitude magnetic field intensity is probably due to the influence of hematite and magnetite while the low magnetic field intensity is likely because of the presence of schist. The study area is faulted with structures trending along the NE –SW, NW – SE, N – S, E – W and NNE – SSW directions, while the most significant feature trending along the NE – SW and NNE – SSW directions. The NE – SW lineaments corresponds with the Atlantic Ocean, the NNE – SSW depicts the Ifewara-Kalangai fault axis while NW – SE represents the separation of Africa from South America which gave rise to the Atlantic Ocean. The intersection between the NW – SE, and NE – SW lineaments implies that these fractures were produced by similar tectonic events. While zones of lineament intersection are feasible zones for groundwater, geothermal and solid mineral prospecting. Areas of weakness are the most probable sources of the seismic energy causing the earth tremors, hence there should be efficient and integrated seismic observatories, so as to monitor and record future seismic events. Also, for the purpose of evaluating the groundwater potential of the study area, geo-electrical survey should be conducted in regions with substantial lineament intersection density. The mapped lineaments would serve as guide in geothermal exploration and solid mineral prospecting.

ACKNOWLEDGEMENT

We wish to acknowledge the efforts of the management of Nigerian Geological Survey Agency (NGSA) in the acquisition of the aeromagnetic Data used in this study. We also wish to thank the Geosoft Inc. for the provision of Oasis Montaj Software which was used in processing the data.

References

[1] D. Vere-Jones, "Forecasting earthquakes and earthquake risk", International Journal of Forecasting **11** (1995) 503. https://doi.org/10.1016/0169-2070(95)00621-4.

[2] Y. Y. Kagan and D. D. Jackson, "Long-term probabilistic forecasting of earthquakes", Journal of Geophysical Research: Solid Earth **99** (1994) 13685. https://doi.org/10.1029/94JB00500.

[3] Y. Ogata, "Statistical models for earthquake occurrences and residual analysis for point processes", Journal of the American Statistical Association **83** (1988) 9. https://doi.org/10.2307/2288914.

[4] Y. Y. Kagan and L. Knopoff, "Statistical short-term earthquake prediction", Science **236** (1987) 1563. https://doi.org/10.1126/science.236.4808.1563.

[5] S. T. Mohammed, U. A. Lar, T. A. Yakubu, D. Dauda & A. K. Umar, "The Review of the historical and recent seismic activity in Nigeria", Journal of Applied Geology and Geophysics **3** (2015) 48. https://doi.org/10.9790/0990-03114856.

[6] K. U. Afegbua, T. A. Yakubu, O. U. Akpan, D. Duncan & E. S. Usifoh, "Towards an integrated seismic hazard monitoring in Nigeria using geophysical and geodectic techniques", International Journal of the Physical Sciences **6** (2011) 6385. https://doi.org/10.5897/IJPS10.375.

[7] A. Adepelumi, B. D. Ako, T. Ajayi, A. Olorunfemi, M. Awoyemi & D. Falebita, "Integrated geophysical mapping of the Ifewara transcurrent fault system, Nigeria", Journal of African Earth Sciences **52** (2008) 161. https://doi.org/10.1016/j.jafrearsci.2008.07.002.

[8] O. David, O. Aurelius Ojaina, K. Umar Afegbua & I. Kelvin Uche, "Geophysical evaluation of central Nigeria Earth tremor activities using high resolution airborne magnetic data", Advances in Research **23** (2022) 23. https://doi.org/10.9734/air/2022/v23i230327.

[9] D. E. Ajakaiye, M. A. Daniyan, S. B. Ojo & K. M. Onuoha, "The July 28, 1984 southwestern Nigeria earthquake and its implications for the understanding of the tectonic structure of Nigeria", Journal of Geodynamics **7** (1987) 205. https://doi.org/10.1016/0264-3707(87)90005-6.

[10] O. U. Akpan and T. A. Yakubu, "A review of earthquake occurrences and observations in Nigeria", Earthquake Science **23** (2010) 289. https://doi.org/10.1007/s11589-010-0725-7.

[11] O. M. Orji & H. O. Nwankwoala, "An overview of earthquakes and tremors in Nigeria: Occurrences, Distributions and Implications for Monitoring", International Journal of Geology and Earth Sciences **4** (2018) 56. https://doi.org/10.32937/IJGES.4.4.2018.56-76.

[12] A. Y. B. Anifowose et al., "Systematic multi-technique mapping of the Southern flank of Iwaraje fault, Nigeria", Journal of Applied Science and Technology **15** (2010) 70. https://doi.org/10.32937/IJGES.4.4.2018.56-76

[13] S. I. Abaa, "The structure and petrography of alkaline rocks of the Mada younger granite complex, Nigeria", Journal of African Earth Sciences **3** (1983) 107. https://doi.org/10.1016/0899-5362(85)90029-6.

[14] A. I. Olayinka, "Geophysical siting of boreholes in crystalline basement areas of Africa", Journal of African Earth Sciences (and the Middle East) **14** (1992) 197. https://doi.org/10.1016/0899-5362(92)90097-V

[15] P. Alken *et al.*, "International geomagnetic reference Field: the thirteenth generation", Earth, Planets and Space **73** (2021) 49. https://doi.org/10.1186/s40623-020-01288-x.

[16] M. N. Nabighian *et al.*, "The historical development of the magnetic method in exploration", Geophysics **70** (2005) 33. https://doi.org/10.1186/s40623-020-01288-x.

[17] J. B. Thurston, R. S. Smith,& J.-C. Guillon, "A multimodel method for depth estimation from magnetic data", Geophysics **67** (2002) 555. https://doi.org/10.1190/1.1468616.

[18] D. T. Thompson, "EULDPH: A new technique for making computer-assisted depth estimates from magnetic data", Geophysics **47** (1982) 1. https://doi.org/10.1190/1.1441278.

[19] W. R. Roest, J. Verhoef & M. Pilkington, "Magnetic interpretation using the 3-D analytic signal", Geophysics **57** (1992) 116. http://dx.doi.org/10.1190/1.1443174.

[20] C. V. Reeves, "The Kalahari desert, Central Southern Africa: a case history of regional gravity and magnetic exploration in the utility of gravity and magnetic surveys", Society of Exploration Geophysics (SEG) **20** (1982) 209. https://doi.org/10.1016/0016-7142(82)90022-9.

[21] C. Reeves, "Aeromagnetic Surveys: Principles, Practice & interpretation", Published by Geosoft (2005) 155.

[22] I. N. MacLeod, K. Jones & T. F. Dai, "3-D analytic signal in the interpretation of total magnetic field data at low magnetic latitudes", Exploration Geophysics **24** (1993) 679. https://doi.org/10.1071/EG993679.

[23] W. M. Telford, L. P. Geldart & R. E. Sheriff, "Applied Geophysics, 2nd Edition.", Cambridge University Press, Cambridge, UK., pp. 353-358, 1990. https://kobita1234.files.wordpress.com/2016/12/telford-geldart-sheriff-applied-geophysics.pdf.

[24] R. O. Hansen, R. Louis & V. J. S. Grauch, "Magnetic method in near surface geophysics" In: Near Surface Geophysics, Society of Exploration Geophysics, D. K. Butler, Ed. Tulsa Oklahoma, U. S. A, 2005, pp. 151 – 175. https://doi.org/10.1190/1.9781560801719.ch6.

[25] E. P. Loehnert, "Major chemical and isotope variations in surface and subsurface waters of West Africa", Journal of African Earth Sciences (and the Middle East) **7** (1988) 579. https://doi.org/10.1016/0899-5362(88)90047-4.

[26] M. Rajaram, S. P. Anand, K. Hemant & M. E. Purucker, "Curie isotherm map of Indian subcontinent from satellite and aeromagnetic data", Earth and Planetary Science Letters **281** (2009) 147. https://doi.org/10.1016/j.epsl.2009.02.013.