Nigerian Research Journal of Engineering and Environmental Sciences 7(2) 2022 pp. 464-475
p ISSN: 2635-3342; e ISSN: 2635-3350

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

Application of Aeromagnetic and Remotely Sensed Data in Mineral Exploration in Parts of Ife-North, Osun State, Southwestern Nigeria

***[1]Osisanya, O.W., [2]Shaibu, O.B., [3]Abolarin, O.M., [4]Eyankware, O.M. and [5]Okpala, E.C.**

[1]Department of Physics, University of Benin, Benin City, Edo State, Nigeria.
[2]Department of Earth Sciences, Kogi State University, Anyigba, Kogi State, Nigeria.
[3]Department of Petroleum Engineering and Geosciences, Petroleum Training Institute, Effurun, Delta State, Nigeria.
[4]Department of Geology, Faculty of Sciences, Ebonyi State University, Abakaliki, Ebonyi State, Nigeria.
[5]Department of Earth Science, Federal University of Petroleum Resources Effurun, Delta State, Nigeria.
*wasiu.osisanya@uniben.edu

http://doi.org/10.5281/zenodo.7496629

ARTICLE INFORMATION

Article history:
Received 12 Sep. 2022
Revised 24 Oct. 2022
Accepted 07 Nov. 2022
Available online 30 Dec. 2022

Keywords:
Aeromagnetic data
Lineaments
Structural trends
Gold deposits
Nigeria

ABSTRACT

This paper analysed aeromagnetic data over parts of the Ilesa schist belt of Nigeria with a view to assessing the sub surface structural settings that might favour mineralisation in the study area using aeromagnetic data and satellite remote sensing imageries. The subsurface lineaments were detected and traced out from the maxima of horizontal gradient magnitude, peaks of analytical signal magnitude. The structural trends of the composite lineament map show predominant lineament directions; NE-SW, NNE-SSW, E-W, and NW-SE. These trends were in agreement with the major regional tectonic trends of Southwestern Nigeria. The interpretation of the aeromagnetic dataset gave an insight into the regional geology and structural trends of the area. The derived lineaments may serve as a reference for future geological and structural mapping. Based on the information gathered so far, the study area shows potential for presence of both primary and alluvial/eluvial gold deposits.

1. INTRODUCTION

Mineral prospectors have a well-known expression that "gold is where you find it," implying that its existence is unpredictable. Certain geological settings are now recognized to facilitate the exploration of

O.W. Osisanya et al. / Nigerian Research Journal of Engineering and Environmental Sciences
7(2) 2022 pp. 464-475

gold. Mineral discovery necessitates a significant investment, consistent cash inflow, and a significant amount of time, while posing a high risk (Tehmina et al., 2016).

Over the last two decades, remotely-sensed spectral reflectance and airborne gamma ray spectrometry data have been used as aids for mapping and mineral prospecting (Kettles et al., 2000). Ofoegbu (1988) reported that about 60% of magnetic surveys are carried out for regional geological mapping and mineral exploration purpose while the remainder being mainly for petroleum exploration. Also, Onuba et al. (2008) pointed out that the main purpose of magnetic survey is to detect rocks or minerals possessing unusual magnetic properties that reveal themselves by causing disturbances or anomalies in the intensity of the earth magnetic field.

The interpretation of aeromagnetic maps involves interpreting the basement structures and detailed examination of structures and lithologic variations in the sedimentary section. Most mineral deposits are related to some type of deformation of the lithosphere, and most theories of ore formation and concentration embody tectonic or deformational concept (Opara 2010). Some lineament patterns have been defined to be the most favourable structural conditions in control of various mineral deposits (Megwara and Udensi, 2013). They include the traces of major regional lineaments, the intersection of major lineaments or both major (regional) and local lineaments, lineaments of tensional nature, local highest concentration (or density) of lineament, between echelon lineaments, and lineaments associated with circular features. Linear features are clearly discernible on aeromagnetic maps and often indicate the form and position of individual folds, faults, joints, veins, lithologic contacts, and other geologic features that may lead to the location of individual mineral deposits. They often indicate the general geometry of subsurface structures of an area thereby providing a regional structural pattern (Onyewuchi et al., 2012).

The study area is characterized by a number of economic mineral deposits which have generated a lot of interest on the economic importance of this mineral zone. Intense geological investigations have been carried out in this area at different times in search for these mineral deposits. Airborne magnetic and radiometric data were used to map the geology and delineated possible gold hosting structure within this part of the belt. This research seeks to review the geology and to aid the delineation of regional and local geological structures (shear zones and faults) that have the potential of hosting gold mineralization within the study area. The work allows the prediction of target areas for detailed exploration work in search for metal ore mineralization within the study area that has not been extensively explored as compared to the other parts of the Ife-Ilesha Belt. This research is aimed at delineation of areas with potential for gold deposits within the study area via the application of geological and remote sensing data to map the structural, lithological, and geophysical characteristics that are peculiar to mineral deposit belts.

2. MATERIALS AND METHODS

2.1. Location of the Study Area

The area is located at about 5 km northwest between Ife and Modakeke town in Osun State, Nigeria (Figure 1). It is situated between 4° 33' 30"E to 4 34'30"E and 7° 29' 30"N to 7° 30' 30N" as shown in Figure 2. The area falls within the Iperindo Gold Metallogenic Province in Nigeria. The area is hosted by Ife/Modakeke communities in Ife North Local Government Area of Osun State.

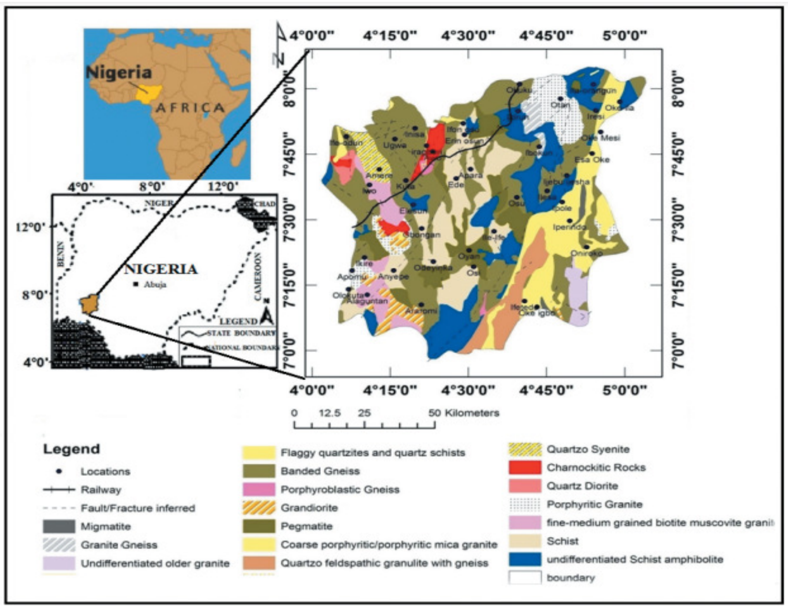

Figure 1: Map of Africa showing Nigeria and Osun State.

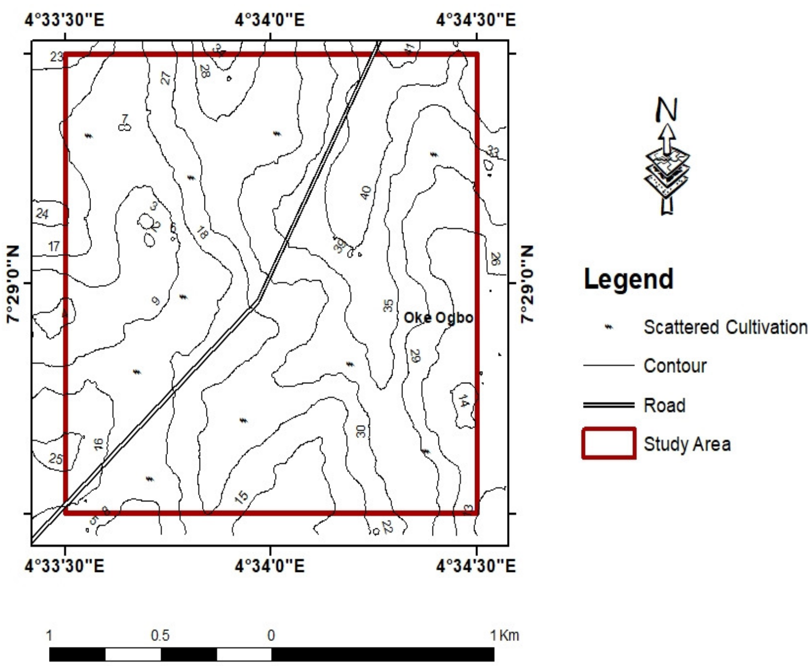

Figure 2: Topographic map of the study area

2.2. Relief of the Study Area

The relief of the area is characterized by a lowland terrain break by ridges of metasediments especially at the southeast of the concession area trending mainly in N-S and NNE and SSW direction. Furthermore, the study area lies mostly on lowlands which are punctuated by rocky outcrops and series of hills (Figure 3). These are mainly of schist and quartzite inselbergs. Some prominent rivers and their tributaries which flow through the state have created some notable river basins. The major rivers include the Ogun, Osun, Oyan, Oba and Ona. The landscape position affects some chemical and physical properties of tropical soils as well as their mineralogy (Lenio et al., 2008).

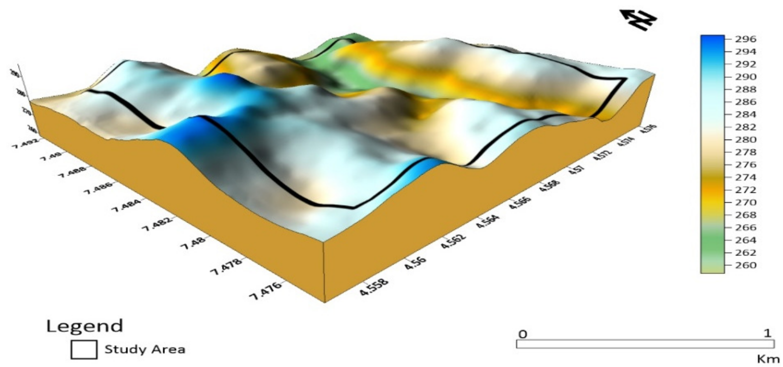

Figure 3: Relief map of the study area

2.3. Aeromagnetic and Radiometric Data Interpretation

Interpretation of aeromagnetic and radiometric data of 1:100,000 sheets 263 (Ondo), South West, Nigeria was carried out with the purpose of picking an area with geophysical anomaly which can be explored for mineralization. The variation of magnetic and radiometric mineral composition in rocks due to the difference in lithological set up and mineralization processes such as hydrothermal mineralization makes the use of this method in mapping rock lithology, structures and mineral zones an important technique.The radiometric datasets retrieving geochemical information on potassium (K), thorium (Th) and uranium (U) concentration areas were used to delineate bedrock lithology as well as alteration and contact zones.

2.4. Airborne Geophysical Data Acquisition

2.4.1. Magnetic data

The airborne survey data was acquired under the following specification: Triaxial magnetic gradiometer – two wingtip and single tail sensors – 10 Hz sampling (~7.5 m), Gamma-ray spectrometer – 1 Hz sampling (~75 m) 500 m line spacing – NW-SE orientation, 2 km control line spacing – NE-SW orientation Nominal 80 m terrain clearance on pre-planned drape surface, Measured horizontal gradients and gradient-enhanced gridding Radiometric NASVD noise reduction. The aeromagnetic data of the survey was available in the form of total magnetic intensity in Figure 4.

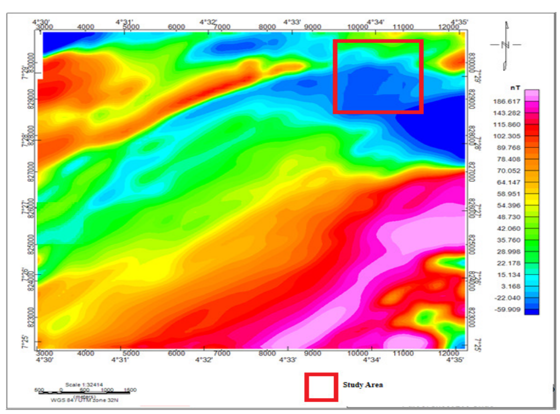

Figure 4: The total magnetic intensity map of the area reduced to the magnetic equator

3. RESULTS AND DISCUSSION

3.1. Aeroradiometric Data

Radiometric datasets were also acquired from Nigeria Geological Survey Agency (NGSA). In order to recognize and understand radiometric signatures associated with the host rocks important to mineralization, enhancing techniques such as composite image, ratio maps as well as potassium (%K), equivalent thorium (eTh ppm) and equivalent uranium (eU ppm) maps were used. The ternary image of the area showing the various concentration of the elements are displayed in Figure 5. Ademila et al. (2018) investigated the radioactive properties of rock using radiometric methods in Southwest Nigeria with the aim of deciphering its geological structure and natural radioactive element embedded in it. It was discovered that moderate to very high concentration and very low concentration of the radioelements; uranium (4.5-13.0 ppm); Th, (25.0-70.0 ppm); (8.5-16.0 ppm) and K (2.0-4.0 %); but the most often observed values are in the range 2.5-7.0 ppm, 22.0-30.0 ppm and 3.0-4.0% for U, Th, and K respectively.

3.2. Digital Elevation Model

Shuttle radar topographic mission data acquired at 30 m resolution describes the elevation of the earth surface. It was successfully recorded by interferometric synthetic aperture radar (InSAR) land mass data ranging between 50N and 57S. The data was acquired in the C- and X- bands were processed into the first global digital elevation models (DEM) at a resolution of 1 arc sec by NASA-JPL and the German aerospace center (DLR). The DEM is displayed in Figure 6. Agunleti et al. (2020) delineated the rock boundaries and structural lineament of North western Nigeria with the application of airborne geophysical and satellite imagery. It was observed that a structural lineament trending NE-SW for almost 25 km as a major trend while NW-SE with few E-W trend as a minor one.

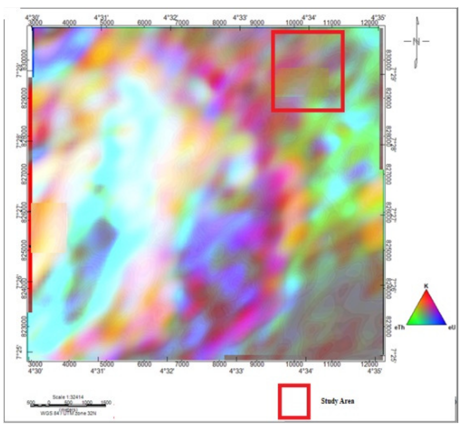

Figure 5: Ternary map of the area showing the various concentration proportions of the potassium, thorium and uranium count over the area

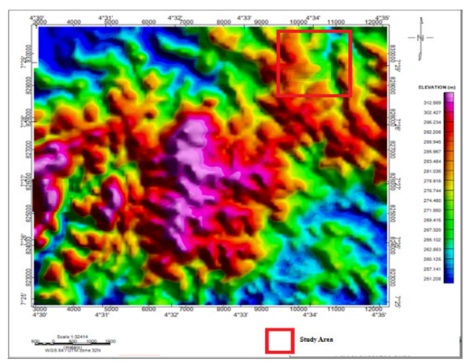

Figure 6: The digital elevation map of the study area

3.3. Aeromagnetic Data

The original total magnetic field intensity (TMI) grid (Figure 4) was processed, filtered and transformed to other grids using Oasis Montaj software with associated extensions of the package such as MAGMAP, SPI, and CET etc. Spatial derivatives such as first vertical derivative (1VD) (Figure 7), second vertical derivative (2VD) (Figure 8), and analytical signal (Figure 9), were computed and analysed. The interpretation was performed on screen in the ArcMap. Quality hardcopy results were produced directly from ArcMap for a qualitative visualization and analysis. Interpretation methodology consists of inspection of computer screen and hard-copy maps of the total magnetic field intensity, first vertical derivative, second vertical derivative, analytical signal (potassium to thorium concentration map (K/eTh) (Figure 9) and ternary radiometric map (Figure 5), According to Dobrin and Savit (1998) and Daniel et al. (2016), the main use of any aeromagnetic

O.W. Osisanya et al. / Nigerian Research Journal of Engineering and Environmental Sciences
7(2) 2022 pp. 464-475

and their derivative maps in mineral prospecting is to make geological deduction from them. From the range of magnetic intensity values of these data, information on subsurface lithology, trend and geological structures can be obtained.

3.4. First and Second Vertical Derivatives

The first and second derivatives (Figures 7 and 8) grids were used in extracting the structures and lineaments since they signify changes of functions or signals in various directions and because they behave like high pass filters, they emphasize near surface structures. Some lineament features were interpreted structurally using satellite image processing (Landsat TM) in Northern Tunisia by Gannouni and Gabtni, (2015). They mapped various direction of lineament from digital satellite scene (Landsat 5, TM data) and compared their results with some geophysical studies conducted in the study area. It was discovered that the major lineaments in the study area are trending NE-SW and NW-SW orientation. In Figure 7, the shaded color aeromagnetic map of the study area varies in amplitude suggesting contrasting rock types in the basement of the study area. The mid-section of the study area is characterized by relatively high magnetic intensity values while the topmost area shows progressively lower magnetic intensity values. In low latitude magnetic region specifically around the equator of which Nigeria is situated, a low negative magnetic peak value represents typical anomalous signatures (Parasnis, 1986; Fieberg, 2002). The NW – SE low amplitude lineament anomaly in the study area Figure 7 may represent fault or fracture zone.

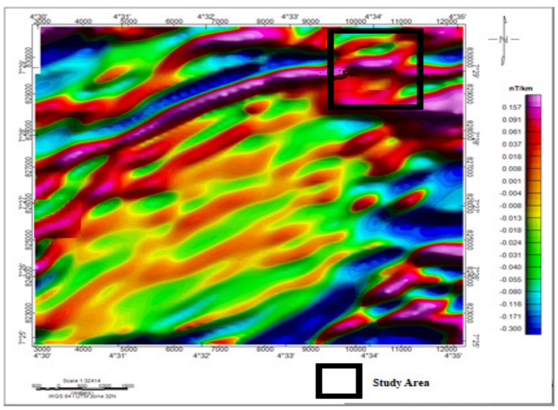

Figure 7: First vertical derivative of the TMI over the area

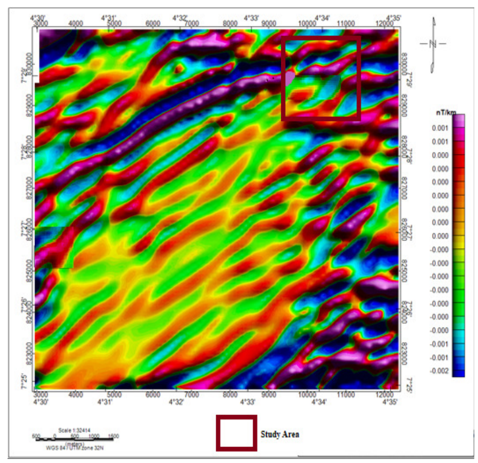

Figure 8: Second vertical derivative of the TMI, emphasizing near surface magnetic structure

The second vertical derivative serves much the same purpose as ‘residual’ filtering in gravity and magnetic maps, in that it emphasizes the expressions of local features, and removes the effects of large anomalies or regional influences. The principal usefulness of this enhancement is that the zero value for gravity data in particular closely follows sub-vertical edges of fractures or faults. (Figure 8). As with other derivative displays, it is particularly helpful in the processing stage where it can be used to highlight line noise or mis-levelling.

3.5. Analytic Signal (Total Gradient)

The width of a maximum, or ridge, is an indicator of depth of the contact, as long as the signal arising from a single contact can be resolved. This transformation is often useful at low magnetic latitudes because of the inherent problems with RTP, (at such low latitudes). The analytic signal, although often more discontinuous than the simple horizontal gradient, has the property that it generates a maximum directly over discrete bodies as well as their edges as shown in the study area. The analytic signal map is presented in Figure 9.

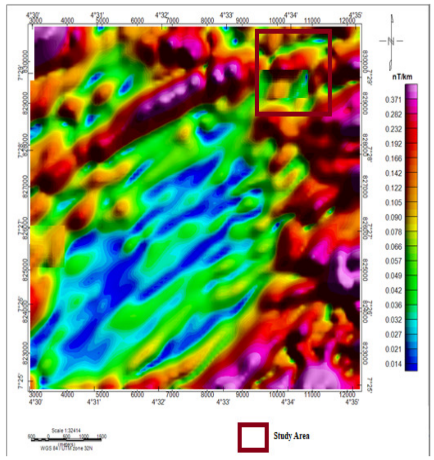

Figure 9: Analytical signal map

3.6. Horizontal Gradient Magnitude (Y-Direction)

The total horizontal derivatives in the Y direction is a derivative in the North-South direction generated from the TMI map (Figure 10). It is also an Edge detection method such as the First and second vertical derivatives. The filter was applied because the lineament trends from the first and second vertical derivatives has trends in the ENE-WSW. This derivative suppresses other bodies of a causative anomaly and enhances the edges in the Y direction. This was used for the trend and orientation analysis of the rocks in the area. Similarly, Musa et al. (2021) conducted a high-resolution aeromagnetic research over the Gongola basin upper Benue trough North Eastern Nigeria with the use of the first horizontal and first vertical derivatives of the data inorder to map the faults and fractures within the study area. The result revealed a thin elongated contact location with major structures in the NE-SW direction via rose diagram and maps.

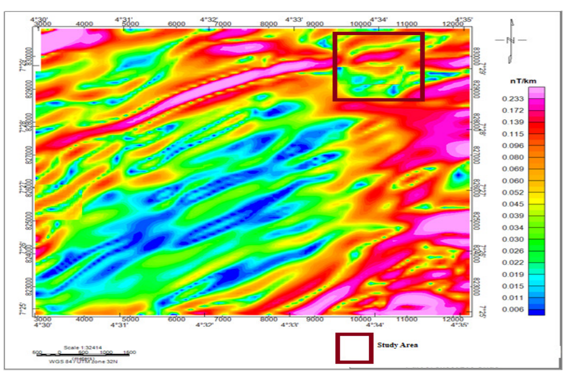

Figure 10: Horizontal gradient map over the area

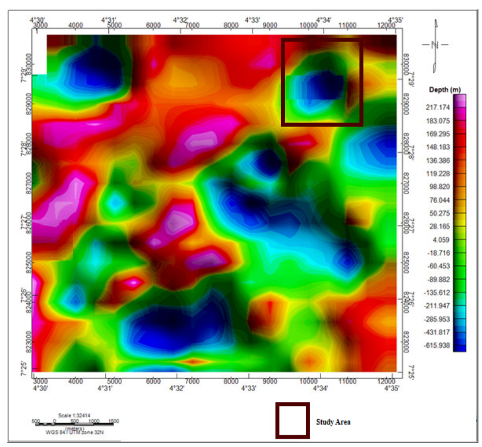

Figure 11: Magnetic source depth map

3.7. Depth to Magnetic Source

The SPI depth grid (Figure 11) was computed in order to estimate depth to magnetic sources. The SPI depth grid show that most magnetic sources are of deeper depth within the study area and the cost of exploration is usually cheaper with shallow depth deposits than for very deep-seated mineral deposits. Odidi et al. (2020) investigated depth to magnetic sources of parts of central and North-eastern Nigeria using source parameter imaging (SPI) as a reconnaissance tool for geothermal research in the study area. The estimated depth to magnetic sources from the SPI was stated to range from 0.12 to 12.26 km with the highest depth located at the south western part of the study area while the north and extreme north-eastern parts of the area constitute the shallow depth with magnetic low.

3.8. Airborne Radiometry

The airborne-radiometric technique assists considerably in mapping surface structure, lithological units and identification of hydrothermal alteration zones (Adepelumi *et al*., 2008). The radiometric data were gridded to obtain total count, potassium, equivalent thorium and equivalent uranium maps to show the surface distribution of these elements and delineate surface lineaments (Figure 12, 13, 14).

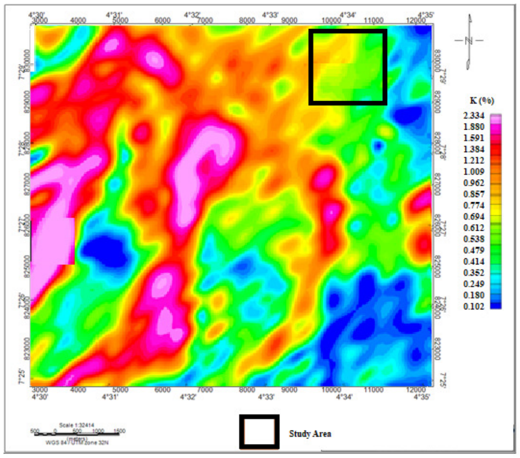

Figure 12: Potassium count map

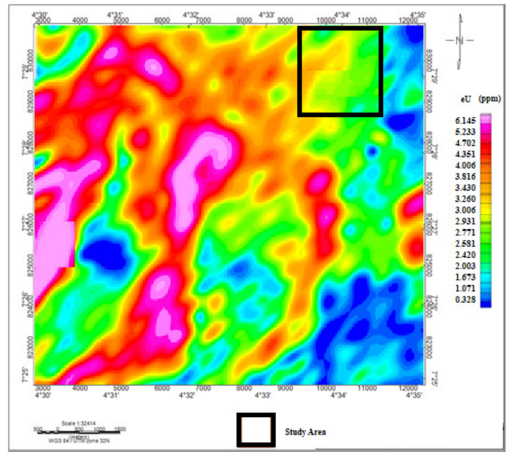

Figure 13: Uranium count map

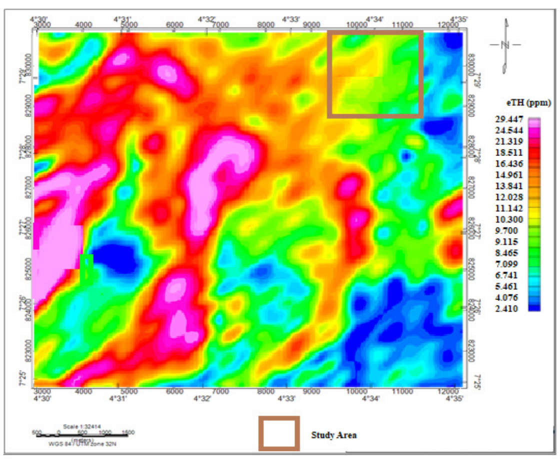

Figure 14: Thorium count map

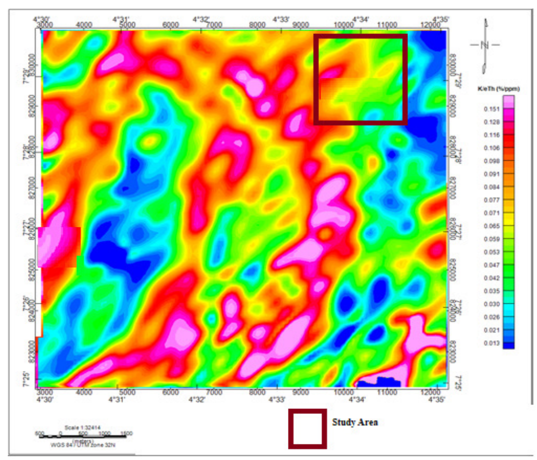

Figure 15: Potassium to thorium ratio map

Also, producing K/eTh ratio map (Figure 15) help to map hydrothermally altered zones, since a reduction in eTh and a rise in K is an indicator of alteration environments in an ore deposit (Figure 12, 13, 14). Sayed and Mahmoud (2018) used airborne magnetic and radiometric data to delineate potential gold deposit in a part of central eastern desert, Egypt. It was discovered that the dominant structural direction in the study area are E-W, N-S, WNW, NNE, NNW and NW whereas NW-SE was found to be the most importance and preferred orientation of ore deposit in the study area.

3.9. Landsat Imagery

The Landsat 8 bands (Figure 16) was engaged due to the geologic information that was obtained from the various combination of bands. First the two major corrections were done; these are the radiometric and the atmospheric correction in a bid to increase the signal ration and reduce the noise ratio for the individual bands. Band rationing which is a common spectral enhancement method used in highlighting characteristic spectral behavior of the material such as rocks, minerals, vegetation based on the spectral reflectance was adopted. Bands within shortwave infrared (SWIR) and thermal infrared (TIR) of the electromagnetic spectrum were computed using the ENVI 5.1 software. This was done because of the ability of these bands to give good and accurate geologic information. The various bands were combined to map Ferric-ion bearing minerals (Hematite, Goethite and jarosite), ferrous-ion bearing minerals (olivine, pyroxenes, amphobolites) and clay, micas, and carbonate minerals (AL=OH, Mg-OH, CO_3).

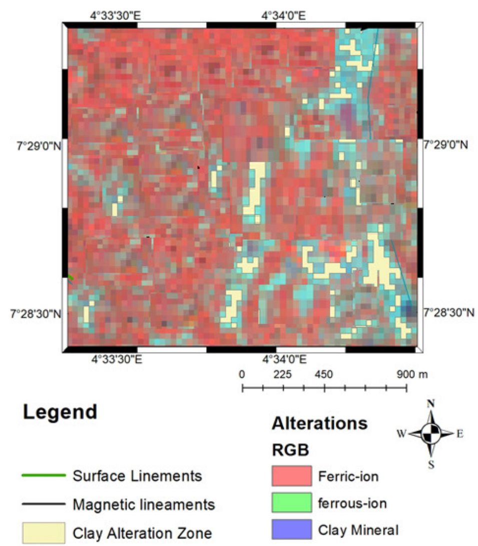

Figure 16: Integrated lithological and structural map with lineament from magnetic data

3.10. Interpretation of Integrated Data

The identified lithological and structural map from the magnetic, radiometric and Landsat data were integrated to identify areas with high potential for gold mineralization within the study area for further ground exploration. The extracted magnetic lineaments were observed to be from deeper occurrence. The underlying geology being schists of both the undifferentiated on the western part and the pegmatized schist on the eastern region. The lineaments analysis of the mapped structures (Figure 17) was carried out and the orientation was determined. The main lineament trend in the region is in the NNE – SSW and in the ENE-WSW, showing the deformation is of different episode and mineralization as most of the latter mineral rich fluid are fracture filled vein type deposit, primary gold area deposits are associated with some schist belts. From the combination of some specific bands on Landsat 8 imagery Al-OH,Mg-OH, OH, and CO_3 bearing minerals such as clay minerals, micas, talc-carbonate usually associated with mineral deposits such as gold. The result of the lineament orientation in the study area is similar to lineament trend discovered in North central Nigeria with NE-SW and NW-SE orientation by Bulus (2021). He discovered that the major structural trend of the rose diagram are NE-SW, NNE-SSW and NW-SE and the structurally directions derived from 2D maps are aligned along NE–SW, NW–SE, N–S and E–W.

O.W. Osisanya et al. / Nigerian Research Journal of Engineering and Environmental Sciences
7(2) 2022 pp. 464-475

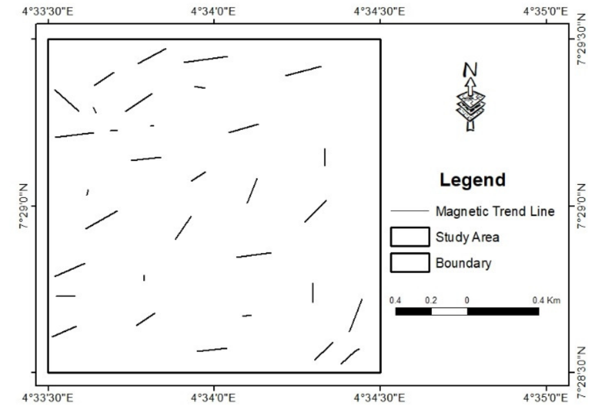

Figure 17: Magnetic lineament map of the study area

3.11. Digital Elevation Model of the Study Area

Digital elevation model (Figure 18) reveals the topography nature of the study area. It is possible that both primary and placer gold deposits may exist within the study area. As a result, the valleys of the study area should be given high priority for alluvial and elluvial gold mining in the area. The majority of the payable alluvial workings in the Ife-Ilesha gold field, according to De Swardt (1953), were confined to the valleys draining the area underlain by the amphibolite complex. The semi-conformable granular quartz veins or sheets in the amphibolites are thought to be the source of these paying workings.

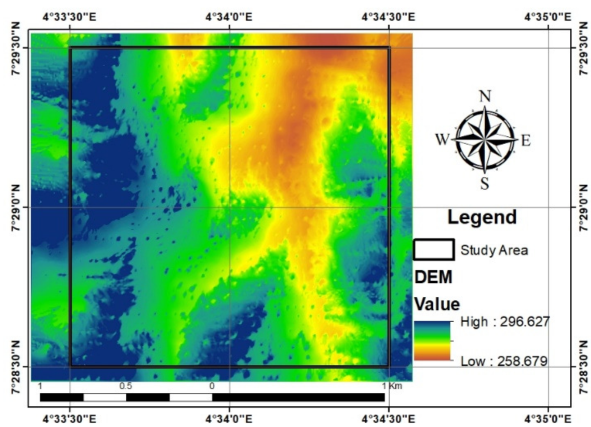

Figure 18: Digital elevation model of the study area

The geology, structure, and alteration zones in the research area were delineated using airborne magnetic and radiometric datasets. The airborne radiometric and magnetic data provided high resolution maps of the area's primary lithology and structural features. The analysis of these maps is intended to identify individual lithology and outline geological features that influence gold mineralization in the area. Elevated radiometric element patterns and low magnetic sensitive areas that may have originated from rock modifications or potential mineral deposits are identified as potential locations for ore deposits.

From the interpreted map (Figure 17), the area has undergone pronounced tectonic activity which resulted in fracturing, faulting and shearing. Some of the lineaments are essentially magnetic unit boundaries which may be lithological boundaries. Such structures interpreted from the aeromagnetic maps are essential channels for mineralization fluids. The Landsat clay mineral alteration (this is because the primary gold deposits in the Ife-Ilesa schists are associated with amphibolite rocks and it get weathered to talc (a clay mineral)) map from the combination of some specific bands were used as an additional information with magnetic alterations, regional and localized aeromagnetic anomalies with associated lineaments, magnetic depletion and Zones with high potassium and low thorium/potassium ratio anomalies indicating potassium enrichment associated with sericitic and/or K-feldspar. More so, the study area is primarily consisting of different mineralization such as pegmatite, schist, granite gnieses and undifferentiated schist amphibolite which make us the geology of the area (Figure 19).

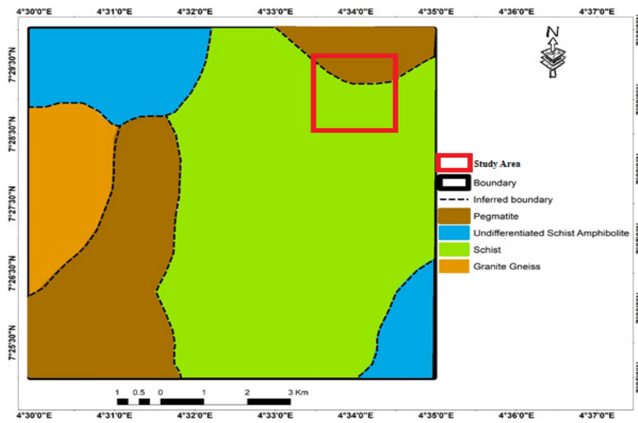

Figure 19: Geologic map showing the study area. (NGSA 2006)

4. CONCLUSION

The application of selected enhancement methods on the magnetic data shows the subsurface structural element in the study area. Although, the interpretation from the aeromagnetic and radiometric data presented here is regional in nature; a common feature of the mineralized veins in the investigated area is in close proximity to major and subsidiary fault structures which can be delineated with such a regional data like this. So, the sheared zone and fractures are potential channels for mineralization fluids. The area has undergone a pronounced tectonic activity resulting in shearing and fracturing. The observed zonation in the magnetic data and the potassic alteration in the ternary image are indication of hydrothermal alteration associated with mineralization. This alteration signature is broad and laterally extensive providing a larger exploration target within the area of interest. However, since the targeted minerals are structurally controlled in veins, fault etc., detailed geological mapping, geochemical mapping and ground follow-up geophysical surveys are highly recommended to be carried out across these anomalies and major lineaments which are suspected to be mineralized veins. For maximum resolution, the traverse orientation in the proposed survey should be perpendicular to the orientation of these indicated structures. According to the evidence acquired thus far, the study area has the potential for both primary and alluvial/eluvial gold deposits. The primary deposit will most likely exist in dispersed form within the area's mafic rocks, particularly the amphibolite, whilst the alluvial deposit may occur in practically all valleys.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Ademila, O., Akingboye, A.S. and Ojamomi, A.I. (2018). Radiometric survey in geological mapping of parts of basement complex area of Nigeria. Vietnam Journal of Earth Sciences, 40(3), pp. 288-298.

Adepelumi, A.A., Ako, B.D., Ajayi, T.R., Olorunfemi, A.O., Awoyemi, M.O. and Falebita, D.E. (2008). Integrated geophysical mapping of the Ifewara transcurrent fault system, Nigeria. *Journal of Africa Earth Science,* 52, pp. 161–166.

Agunleti, Y.S., Najime, T., Ibrahim, A.A. and Magaji, S.S. (2020). The Application of Airborne Geophysical and Satellite Imagery Data in the Delineation of Rock Boundaries and Structural Lineaments in Anka Sheet 52, Northwestern, Nigeria. *Journal of Environment and Earth Science*, 10, pp. 1-9.

Bulus, J.A. (2021). Mapping and Analysis of the Density of Lineaments of the Younger Granite Complexes of Jos and Environs, North Central Nigeria. *Science World Journal*, 16(3), pp. 272-279.

Daniel, N.O., John, A.Y., Francisca, N.O., Josiah, U.C. and Andrew, I.O. (2016). Interpretation of Aeromagnetic Data of Idah Area in North Central Nigeria Using Combined Methods. *Journal Geological Society of India*, 88, pp. 98-106

De Swardt, A.M.J. (1953). The geology of the country around Ilesa. *Bulletin of the Geological Survey of Nigeria.* No. 23.

Dobrin, M.B. and Savit, C.H. (1998). *Introduction to Geophysical Prospecting*. McGraw-Hill Book Co. Inc. New York.

Fieberg, F. C. (2002). Ground magnetic investigations for gold prospecting in south-western Nigeria. Presentation given at the 62nd Meeting of the German Geophysical Society, Hannover.

Kettles, M., Rencz, A.N. and Bauke, S.D. (2000). Integrating Landsat, Geologic, and Airborne Gamma Ray Data as an Aid to Surficial Geology Mapping and Mineral Exploration in the Manitouwadge Area, Ontario. *Photogrammetric Engineering & Remote Sensing*, 4, pp. 437-445.

Lênio, S.G., Antônio, R.F., Eduardo, G.C.N. and Dar, A.R. (2008). Relationships between the mineralogical and chemical composition of tropical soils and topography from hyperspectral remote sensing data. *Journal of Photogrammetry & Remote Sensing* 63, pp. 259–271

Megwara, J.U. and Udensi, E. E. (2013). Lineaments study using aeromagnetic data over parts of southern Bida basin, Nigeria and the surrounding basement rocks. *International Journal of Basic and Applied Sciences,* *2*(1), pp. 115-124.

Musa, H., Bello, R., Raheem, I. O. and Abe, A.O. (2021). First Horizontal and First Vertical Derivatives from High Resolution Aeromagnetic Data Over the Gongola Basin Upper Benue Trough Northeastern Nigeria. *Global Journal of Pure and Applied Sciences,* 27, pp. 181-192

Nigeria Geological Survey Agency (NGSA). (2006). The geological map of Nigeria. Abuja: NGSA.

Odidi, I. G., Mallam, A. and Nasir, N. (2020). Depth to magnetic sources determination using Source Parameter Imaging (SPI) of aeromagnetic data of parts of Central and North-Eastern Nigeria: a reconnaissance tool for geothermal exploration in the area. *Science World Journal*, *15*(3), pp. 19-23.

Ofoegbu, C.O. (1988). An aeromagnetic study of part of the upper Benue Trough Nigeria. *Journal of African Earth Science*, 7, pp. 77-90.

Opara, A. I. (2010). Second Vertical Derivatives and Trend Surface Analysis of the Aeromagnetic Data Over Part of the Benin Basin, Nigeria. *Global Journal of Geological Sciences,* 9(1), pp. 19-26.

Onuba, L.N., Onwuemesi, A.G., Anudu, G.K., Chiaghanam, O.I. and Ifelunni, C.D. (2008). Interpretation of aeromagnetic anomalies over Benue Trough, Northeastern, Nigeria. *Journal of Natural and applied sciences*, 9, pp. 1-12.

Onyewuchi, R.A., Opara, A.I., Ahiarakwem, C.A. and Oko, F. U. (2012). Geological Interpretations Inferred From Airborne Magnetic and Landsat Data: Case Study of Nkalagu Area, Southeastern Nigeria. *International Journal of Science and Technology, 2*(4) pp. 178-191

Parasnis, D. S., (1986). *Principles of Applied Geophysics*. Chapman Hall, London, pp. 43-44.

Sayed, O.E. and Mahmoud, A.G.A. (2018). Delineation potential gold mineralization zones in a part of Central Eastern Desert, Egypt using Airborne Magnetic and Radiometric data. *NRIAG Journal of Astronomy and Geophysics*, 7, pp. 119-127.

Gannouni, S. and Gabtni, H. (2015). Structural interpretation of lineaments by satellite image processing (Landsat TM) in the region of Zahret Medien (Northern Tunisia). *Journal of Geographic Information System*, *7*(02), p. 119.

Tehmina, K., Trang, N., Franziska, O. and Richard, S. (2016). From Commodity Discovery to Production. Policy Research Working Paper 7823, September 2016.