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ASSESSMENT OF STRUCTURES AND DEPTH TO MAGNETIC SOURCE IN THE SOUTHERN PART OF KATSINA STATE USING AEROMAGNETIC DATA

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ABSTRACT: *The discovery of oil and the subsequent oil boom in Nigeria, which began in 1960, have resulted in the country's complete reliance on oil and the neglect of other economic sectors, particularly the mineral industry, which would have caused a spike in the nation's revenue production. The study area lies within the Northern Nigeria Basement complex. This study aimed to delineate geological lineaments and estimate the depth to magnetic source using two aeromagnetic Sheets (Sheet 78 Funtua and Sheet 79 Malumfashi) that were provided by the Nigerian Geological Survey Agency (NGSA) in Abuja. Consequently, the objectives of this research are to produce a composite total magnetic intensity (TMI) map of the study area, to identify prominent structural lineaments and their trends in the study area using the first vertical derivative, to identify magnetic source location using the analytic signal method and to estimate the depth to magnetic source within the study area using the analytic signal method. From the results, the first vertical derivative map of the study area accentuated the short wavelengths within the study area revealing the structures. Structures are predominant within the northeastern part of the area down to the south along the eastern edge of the area. The analytic signal within the study area varies from 0.003 nT/m low amplitude to 0.194 nT/m high amplitude. The analytic signals within this study area have been grouped into three classes (low, medium, and high). The low analytic signal amplitude ranges from 0.003 nT/m to 0.035 nT/m, the medium analytic signal class ranges from 0.035 nT/m to 0.114 nT/m, and the high analytic signal values are greater than 0.114 nT/m. The depth to the magnetic source here varies from deep sources (657.991 m) to shallow sources (12.725 m). Zango Bayaro, Maigunya, Barga, Dan Maiki, Kuka, Tudun Wada, Tugen Na'alma, Dan Mani, Jankollawa, Dadin Kowa and Kofar Fada have been shown to have shallow depth to magnetic sources. Mai Kandamba, Funtua, Kankara, Malumfashi, Dan Sare, Kumbawa, Unguwar Tofa, Pada and Dorobo are areas with the deepest magnetic sources.*

KEYWORDS*:* Magnetic source, analytic signal, structures, Amplitude and vertical derivative.

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INTRODUCTION

The study of the physical properties of the earth is the subject of the scientific discipline known as geophysics. During the process of investigating the subsurface of the earth, signals are transmitted into the earth and measurements are taken. After travelling through the interior of the earth, the signals are affected by the internal distribution of the earth's physical properties (Kearey *et al*., 2002). This occurs as the signals propagate through the earth. Among the many geophysical survey methods, some of the most common ones are gravity, magnetic, electromagnetic, seismic, and electrical. According to Kearey *et al.* (2002), every single one of the survey methods possesses a distinct operative physical property. These properties include geothermal density, magnetic susceptibility, radioactivity, propagation of velocity of seismic waves, and electrical conductivity. The subsurface geology of a region of interest has been investigated using these methods throughout the past. There is still the possibility of employing some of these techniques by flying geophysical equipment, specifically magnetic, electromagnetic, radiometric, and gravity technologies. According to Desmond (2015), airborne geophysics is an efficient method for scanning a very large area in a short amount of time for regional exploration.

According to Akanbi (2015) and Telford *et al.* (1990), the objective of a magnetic survey is to investigate the subsurface geology by making use of anomalies in the magnetic field of the Earth that are brought about by the magnetic properties of the rocks that lie beneath the surface. Although the majority of the minerals that form rocks are not magnetic, certain types of rocks contain sufficient amounts of magnetic minerals to produce magnetic anomalies that are noticeable (Tawey *et al*., 2020). Magnetic surveying can be utilized for a wide variety of purposes, ranging from small-scale engineering or archaeology searches to search for buried metal objects to large-scale searches to search for local geological features such as lineaments. It is possible to carry out a magnetic survey either on land, at sea, or high in the air. Additionally, the effectiveness of airborne surveys makes the technology particularly appealing in the search for various types of ore deposits that contain magnetic minerals. The technology is utilized in a wide range of applications. When conducting magnetic surveys, one can either look for magnetic bodies directly or look for a magnetic material that is associated with an interesting target. It is possible, for instance, for magnetic minerals to be present in fractures or faults (Wadhah, 2020; Telford *et al.,* 1990).

Due to differences in the geomagnetic field, magnetic methods search for the probe of the geology of a specific area. These differences are caused by the magnetic characteristics of the rocks that are located beneath the surface (Ge *et al.*, 2020; Olasunkanmi *et al.*, 2020; Kearey *et al.,* 2002). According to Murthy (2007), the aeromagnetic survey is a common type of airborne geophysical survey that has been acknowledged as a primary mapping tool for materials that are strongly magnetized.

There is a wide variety of rocks in the natural world that possess magnetic properties. These rocks may have magnetization that was brought in by the geomagnetic field, magnetization that was left over from a previous time, or a combination of the two. By mapping the patterns of magnetic anomalies that are linked to rock anomalies, it is possible to conduct in-depth investigations of large geological areas at a cost that is minimal per unit area. Only anomalies that originate from the magnetic basement are affected by the maximum distance between the source and magnetometer that is imposed by the magnetic source rock (Grauch & Millegan, 1998). This distance causes anomalies to be reduced in amplitude and extended in wavelength.

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Using aeromagnetic surveys, it is therefore possible to determine the distribution of bedrock lithology and structures in virtually any location. After that, magnetic anomaly patterns can be interpreted to produce maps of hidden geology, which can then be used to guide the exploration process. According to Grant (1985), magnetite is the magnetic mineral that is found in nature the most frequently on a global scale. The other magnetic minerals can probably be ignored. An aeromagnetic survey can be used to map the magnetite that is present in the rocks that are beneath the aircraft. Aeromagnetic surveys are frequently used as reconnaissance instruments; however, due to the unique information that they provide, there has been a growing recognition of their utility for evaluating potential sites since they were first established. Sharma (1987) provided the following description of the functions that aeromagnetic surveys serve:

i. identification of recent lithology in severely metamorphosed terrains or under sand or other recent cover when they are otherwise unrecognizable.

ii. recognizing and interpreting faulting, sharing, and fracturing not only as a potential host for a range of minerals but also as a suggestive indicator of epigenetic stress-related mineralization in the neighbouring rocks.

iii. post-tectonic intrusions are recognized and defined. Zoned syenite or carbonatite complexes, kimberlites, tin-bearing granites, and mafic intrusions are examples of these.

iv. direct discovery of certain iron ore deposits.

The ability to detect and characterize the size of sedimentary basins can be accomplished through the utilization of aeromagnetic data in the search for oil. This is accomplished by providing information on the depth to basement rocks. Dobrin *et al.* (1988) found that almost all variations in magnetic intensity that can be measured at the surface are caused by lithologic or topographic changes related to the basement or by igneous intrusions. This is because igneous rocks have a stronger magnetic strength than sedimentary rocks' magnetic strength.

Nigeria's complete dependence on oil and the neglect of other economic sectors, particularly the mineral industry, which would have caused a spike in the nation's revenue production, are the results of the discovery of oil and the subsequent oil boom that began in 1960. This has led to the country's complete dependence on oil. For instance, the Tin and Columbite discovery in Jos was abandoned in the hands of artesian miners, which resulted in a significant increase in the number of young graduates searching for employment. Rather than being based on a single commodity, the economy needs to be more diversified and must transition to a more diversified economy. The primary objective of this study is to identify the lineaments that are present in the area under investigation and to determine the potential depth of occurrence of these lineaments. Areas of rock deformation, such as faults, folds, joints, and fractures, are essential resources for building foundations and other types of civil engineering projects. These lineaments, which may be linear and continuous features on a magnetic map, may depict these zones of rock deformation. If the lineaments in the study area are properly understood, their delineation and further analysis can provide a clue as to the availability and abundance of ore minerals in the study area. These minerals, if exploited, have the potential to serve as an additional source of income for the country, which is currently solely dependent on oil. Organizations and governments can develop policies for its utilization with the assistance of the information gleaned from the research.

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A series of research have been published within the western half of Nigeria for structural delineation (Akpaneno & Tawey, 2024a; 2024b; Dzukogi *et al.*, 2022; Arogundade *et al.*, 2021; Tawey *et al.*, 2020).

AIM AND OBJECTIVES OF THE STUDY

The aim is assessment of structures and depth to magnetic source in the southern part of Katsina State using aeromagnetic data. The objectives are to:

i. Produce a composite total magnetic intensity (TMI) map of the study area.

ii. Identify prominent structural lineaments and their trends in the study area using the first and second vertical derivatives.

iii. Identify magnetic source location using the analytic signal method and.

iv. Estimate the depth of the magnetic source within the study area using the analytic signal method.

LOCATION, EXTENT AND TOPOGRAPHY OF THE STUDY AREA

The study area is located within the Southern part of Katsina State (Figure 1) and is bounded by latitude 11° 30' N to latitude 12° 0' N and longitude 7° 0' E to longitude 8° E. It is bounded to the North by Kankara, Tsamer, Jekareda and Mabai; Funtua, Umaru, Jiba and Tahida to the South; Mai Gura, Shemi, Dan Tauro and Dan Maiki to the West; and Magaje, Bari, Unguwar Tofa and Zanginawa to East. Figure 2 represents the Shuttle Radar Topographic Mission (SRTM), and Digital Elevation Model (DEM) showing the topographic variation of the study area.

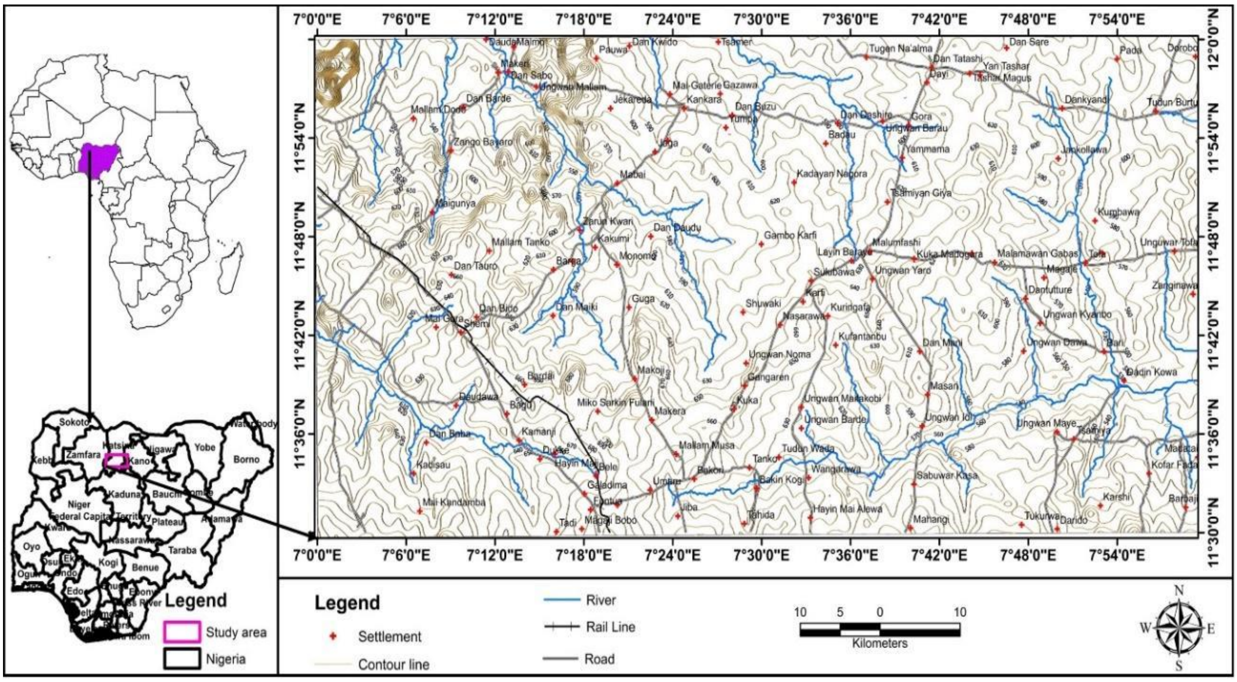

Figure 1: Location map of the study area

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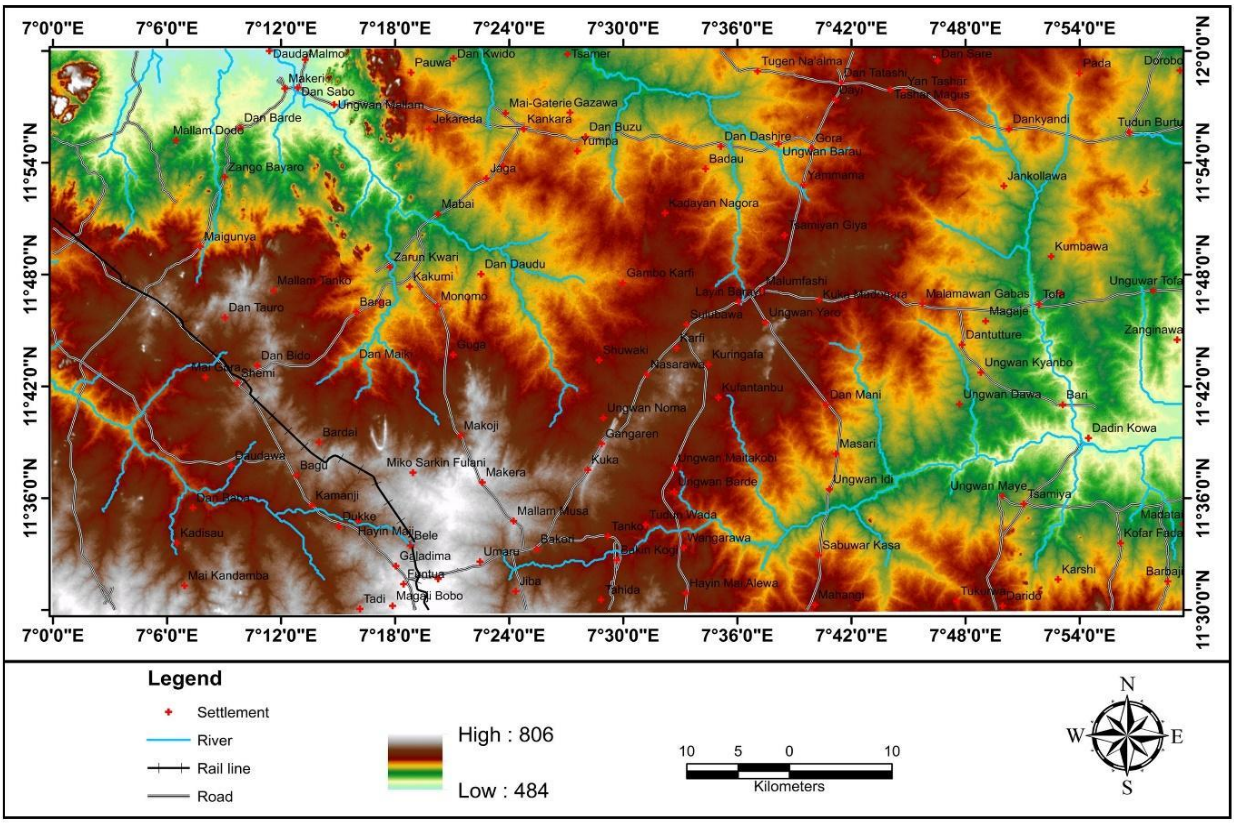

Figure 2: SRTM digital elevation map showing the topographic variation of the study area

The topography within this area ranges from 484 m low specifically around Mallam Dodo, Dan Barde, Zango Bayaro, Magaje, Bari and Zanginawa to 806 m high above sea level specifically around Funtua, Dan Tauro, Guga, Pada, Darido, Nasarawa and Dan Tatashi.

GEOLOGY OF THE AREA

In general, the rocks that make up Katsina State are composed of the following primary units: the Basement Complex, which is composed of migmatite and gneiss; younger metasediments and metavolcanics; granites and younger granites; igneous rocks; and sedimentary rocks (Ibrahim, 1990). There are portions of the state that are buried beneath granites, and some of these granites have lateritic capping. According to Kogbe (1975), some rocks belong to the Daura Igneous Complex, as well as the Gundumi and Chad sedimentary formations. There is a small exposure of softer gneisses and semi-pelitic rocks in some stream channels, but the outcrops are almost entirely composed of resistant migmatites, quartzites, conglomerates, and granites from the outcrops. The majority of the rocks in the Basement Complex are composed of migmatite and gneiss, according to the research and findings of McCurry (1970). The younger metasediments are the second most abundant type of rock in the state, accounting for approximately 33% of the total land area. On the other hand, the granites cover the majority of the western portion of the state. In addition, there is the Chad Sedimentary Formation and the Gundumi Formation, both of which take up approximately 15% of the total land area in Katsina

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State itself. The Daura Younger Granite rocks, which are found in the Zango Local Government Area of the state, are the rocks that are least exposed. Rahaman (1971) found that the contact relationship between the majority of the rocks could only be inferred since the exact contacts between the rocks were concealed by the material that was placed on top of them.

The basement rocks in the study area include:

- Gneiss granite rocks were specifically observed around Pauwa, Dan Kwido, Jakareda, Jaga, Mabai and Dan Dauda.
- Biotite and muscovite schist rock were specifically observed around Mallam Dodo, Zango Bayaro, Pada, Tofa and Kumbawa.
- Biotite and biotite-hornblende granite rocks were specifically observed around Barga and Zarun Kwari.
- Coarse porphyritic/porphyroblast granite rocks were specifically observed around Maigunya, Dan Barde, Mahangi, Tukurwa, Tsamiya, Dadin Kowa and Unguwar Tofa.
- Fine-grained biotite granite rock is not found in any settlement.
- Medium to coarse-grained hornblende biotite granite rock is not found in any settlement.
- Migmatite rock specifically was observed around Jiba, Funtua, Dan Tatashi, Dan Sare and Mallam Tanko.
- Silicified sheared rocks were specifically observed around Nasarawa and Yammama.
- Undifferentiated schist including gnesis were specifically observed around Badau, Malumfashi, Masari, Hayin Mai Alewa and Darido.

These rock types are displayed in Figure 5 below:

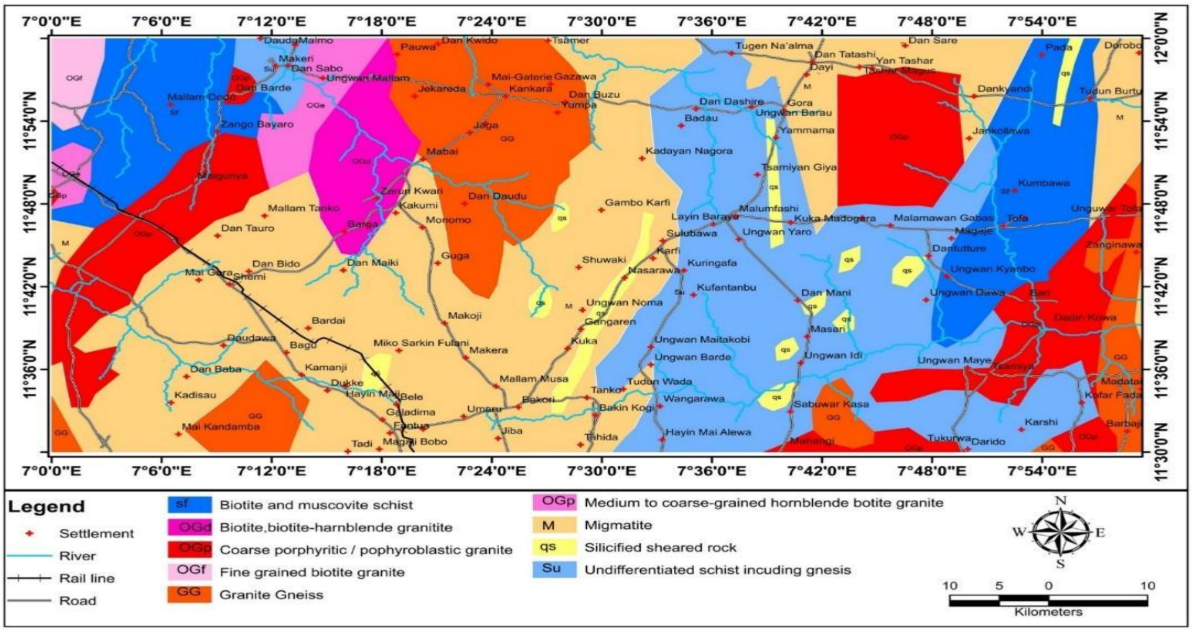

Figure 3: Geologic map of the study area

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MATERIALS AND METHODS

Source of Data

For this investigation, the Nigerian Geological Survey Agency (NGSA) in Abuja was the source of the two aeromagnetic datasets of Funtua-sheet 78 and Malumfashi-sheet 79. At the request of the Nigerian Geological Survey Agency (NGSA), Fugro Airborne Surveys carried out the surveys in the year 2009. Recordings of the data for magnetic measurements were made at intervals of 0.1 seconds, which is equivalent to approximately 7.5 meters. In the direction of the northwest to the southeast, the airborne survey was flown in a direction that was perpendicular to the major geological trends in the region. The flight line spacing was 500 meters, the terrain clearance was 80 meters, and the tie line spacing was 2000 meters. The anomalies are resolved at a much higher level than they would be in a typical high-altitude aerial survey due to the extremely brief recording period, the closer together flight line spacing, and the lower survey flight height of 80 meters.

Methodology

The research project was achieved through the following steps:

- Production of a total magnetic intensity map (TMI) of the study area using Montaj software's.
- Regional and residual data separation maps.
- Production of the reduced-to-the-pole (RTP) map.
- Qualitative interpretation of the (TMI) map produced to identify regions of magnetic lows and magnetic high faults and magnetic lineaments.
- Performing the first and second vertical derivatives of the (TMI) to enhance shallow geological features within the study area.
- Analytical signal depth determinations using TMI data from the study area.
- Depth to magnetic source evaluation using the analytic signal method.
- Detection of structures (lineaments) within the study area from the first vertical derivative of the TMI.
- Carrying out trend analysis using the rose diagram.

Regional-Residual Separation

All of the magnetic fields that are produced by subsurface sources are included in the magnetic data that is obtained from geophysical surveys. The composite map contains two significant anomalies, which are referred to as disturbances. These anomalies are regional patterns and local patterns. On the other hand, local disturbances are secondary in relevance but primary in significance, whereas regional patterns are smooth trends that span large areas. It is necessary to filter these residual anomalies to conduct additional research on them because they might provide direct evidence of reservoir-type structures or mineral ore deposits. These magnetic fields are utilized in the process of creating the composite map.

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Production of Regional and Residual Maps

Several methods can be utilized to get rid of the undesirable regional field. Some of these methods include the polynomial method, the analytical method, the graphical method, the least square method, and the upward continuation method. For this investigation, the residual magnetic intensity data of the study area was derived by subtracting the regional field from the total magnetic intensity data using the upward continuation method. Because of its subjectivity and the fact that the data can be continued upward to any height that is desired, the upward continuation method was ultimately chosen.

Reduction to Magnetic Pole (RTP)

With the help of a technique known as reduction to the pole, one can generate a magnetic map that would have been produced if a region had been surveyed at the magnetic pole (Yaoguo & Douglas, 2001). This would have been the case if all of the magnetic fields that were measured in the study area were caused by induced magnetic effects. The technique is a method for reducing the degree to which the magnetic data is dependent on the angle of the magnetic inclination. Using this filter, data obtained while the earth's magnetic field was inclined is transformed into data that would have been obtained if the magnetic field had been vertical (Li, 2008). Because it will result in a symmetrical abnormality over a non-remanent body that is dipping vertically, a reduction to the pole transform is utilized as an interpretation aid in certain situations. On the other hand, an amplitude correction is necessary at low latitudes to prevent signals from the north and south from taking precedence over the data.

The reduction to the pole is:

$$L(\theta) = \frac{1}{(\sin I_a + i\cos I.\cos(D-\theta))}^{2} \tag{1}$$

where I = geomagnetic inclination, I_a = Inclination for amplitude correction (never less than I) and D = geomagnetic declination Parameter: I_a = Inclination to use for the amplitude correction. The default is □ 20. (I_a= 20, if I □ 0; I_a= (-20) if I □ 0). If I_a is specified to be less than I, it is set to I.

Reduction to the pole has an amplitude component (the sin (I) term) and a phase component

(the icos (I) cos (D – 0) term). When reduced to the pole from equatorial latitudes, the North-South feature can blow up due to the strong amplitude correction (the sin (I) term) that is applied when D – 0 is $\pi/2$ (i.e., a magnetic east-west wavenumber).

Vertical Derivative

A derivative usually makes shallow features more prominent and sharpens the margins of anomalies. The vertical derivative map typically provides a crisper picture than the total field map because it responds to local influences much more quickly than wide or regional ones.

Vertical derivative

$$L(r) = r^n \tag{2}$$

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where n is the differentiation order and r is the wavenumber (radians/ground unit). Note: r = 2pk where k is cycles/ground unit. The ground unit is the survey ground unit used in your grid (e.g., meters, feet, etc.).

The vertical derivative is frequently used to enhance the shallowest geology sources in total magnetic field data. You frequently need to use low-pass filters to get rid of high-wavenumber noise, much like with other filters that improve the high-wavenumber spectrum components.

Analytic Signal

A bell-shaped symmetrical function that maximizes over the top of the magnetic contact is utilized by the filter on magnetic data to assist in the identification of the precise location of the causal body (Nabighian, 1972). Additionally, the three-dimensional case was calculated by Nabighian in 1984. This particular function is a representation of the amplitude of the analytic signal. The only assumptions are that all causal bodies have uniform magnetization and that their cross-sections can be represented by polygons with either finite or infinite depths. These are the only two assumptions included. Because of this, neither this function nor its derivative is dependent on the strike price.

The 3D analytic signal (A) of a potential field anomaly can be defined as:

$$A(x, y, z) = \left[\frac{\partial M}{\partial x}\right]x + \left[\frac{\partial M}{\partial y}\right]y + [\frac{\partial M}{\partial z}]z \qquad (3)$$

where M = magnetic field

The depths of the magnetic sources are estimated under the assumption that the anomalies are in two dimensions (2–D). Hence, the depths of the magnetic source anomalies are estimated as given in the Equation 3.5 below:

$$AS1 = \sqrt{\left(\frac{\delta fv}{\delta x}\right)^2 + \left(\frac{\partial fv}{\partial y}\right)^2 + \left(\frac{\delta fv}{\delta z}\right)^2} \qquad (4)$$

$$D = \frac{AS}{AS1} * N$$

where fv = First vertical derivative of the residual map, D = Depth to the magnetic sources,

AS = Analytic signal of the residual grid, AS1 = Analytic signal of the first vertical derivative of the residual grid, N = 1 (contact), N = 2 (dike), N = 3 (pipe), and N = 4 (sphere) (Baranov, 1957).

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RESULTS AND DISCUSSIONS

TOTAL MAGNETIC INTENSITY (TMI) MAP

Figure 4 represents the TMI map of the study area. It can be observed from the map that most of the anomalies between Zango Bayaro, Maigunya, Mai Kandamba, Barga, Dan Maiki, Funtua, Kuka, Kankara, Tudun Wada, Tugen Na'alma, Malumfashi, Dan Mani, Dan Sare, Jankollawa, Kumbawa, Unguwar Tofa, Dadin Kowa, Kofar Fada, Pada and Dorobo trend in the NE-SW direction and the magnetic intensity ranges from 32903.5 low to 33044.3 nT high. Low (weak) magnetic intensity is portrayed in (blue to green colours) and is observed in areas around Mai Kandamba, Dan Maiki, Funtua, Kankara, Malumfashi, Dan Mani, Jankollawa, Kumbawa, Dadin Kowa and Pada, while the high (strong) magnetic intensity is portrayed in (red to pinkish colouration) and observed at areas around Zango Bayaro, Maigunya, Barga, Kuka, Tudun Wada, Tugen Na'alma, Dan Sare, Unguwar Tofa. Kofar Fada and Dorobo.

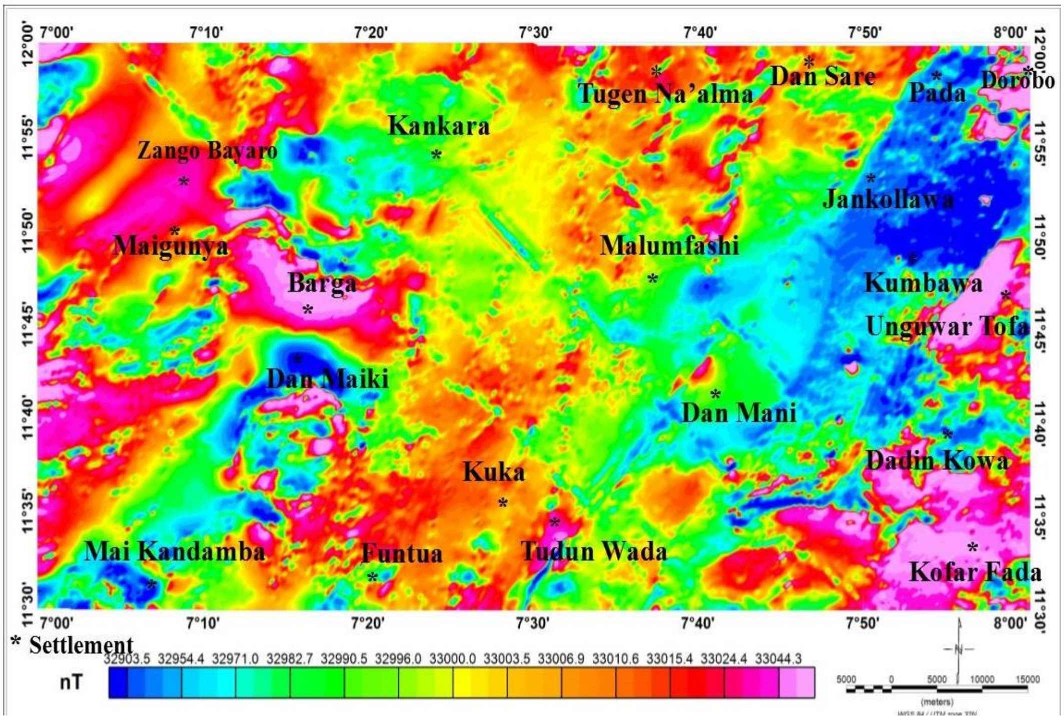

Figure 4: Total magnetic intensity map of the study area

REGIONAL AND RESIDUAL MAGNETIC INTENSITY MAPS

Figure 5a displays the regional magnetic intensity map of the study area with an observed anomaly trend of NW-SE. Also, the regional magnetic intensity values on this map range from 329921.929 nT to 33004.066 nT. The regional map reveals a dominant NW-SE trend in confirmation with Ball (1980) and Olasehinde *et al*. (1990) who discussed the presence of NW-SE regional patterns of aeromagnetic signature within the Nigerian basement complex based on the interpretation of aeromagnetic data. The trend in the regional map is due to the influence of deeper heterogeneity of the crust. Figure 5b represents the residual magnetic intensity (RMI) map.

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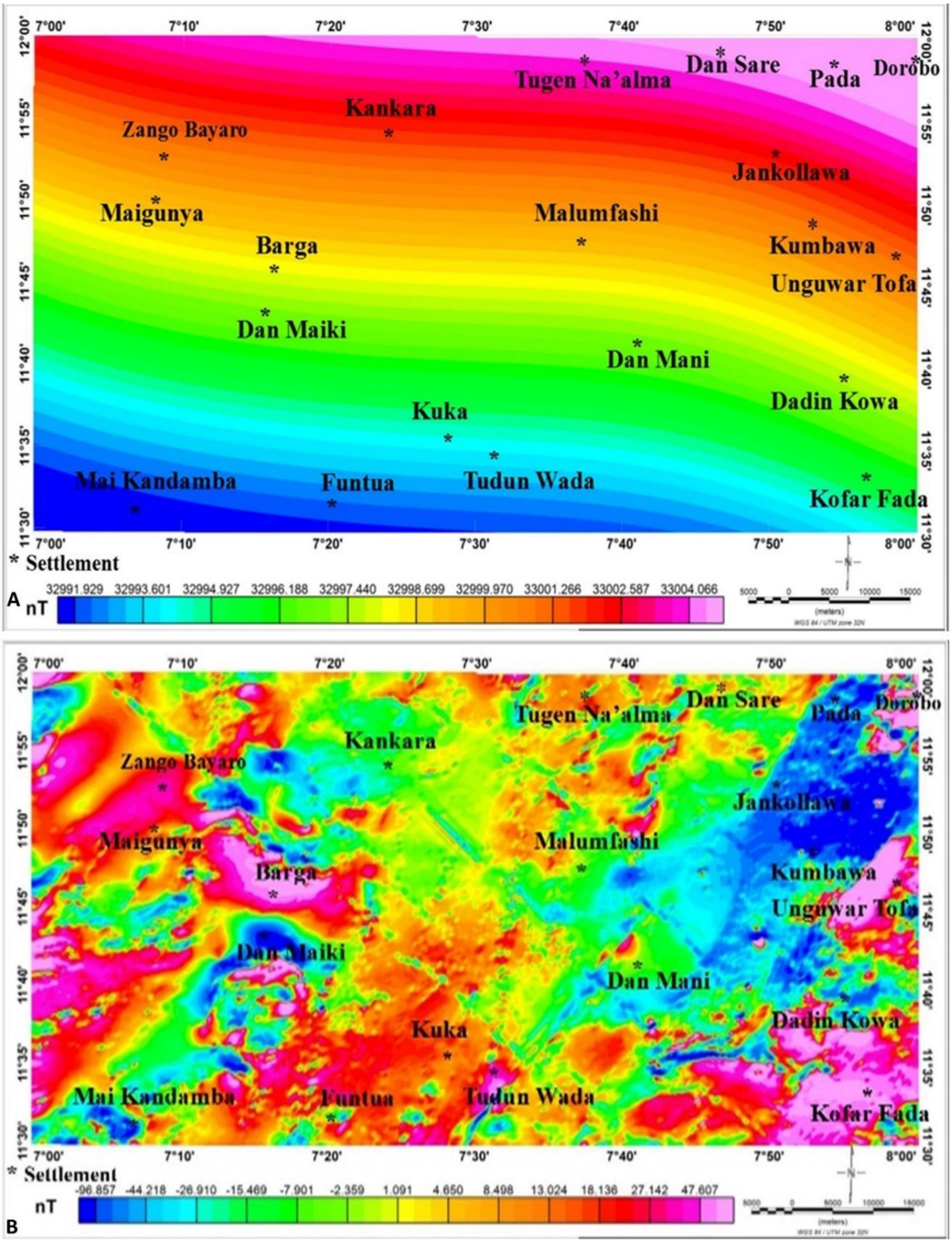

Figure 5: a. Regional map of the study area, and b. Residual magnetic intensity map of the study area

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Magnetic anomalies on this map trend majorly in the NE-SW direction just like the TMI map (Figure 4) and the magnetic intensity ranges from -96.857 nT low to 47.687 nT high; the high (strong) magnetic anomalies portrayed in pink to yellow colours were observed at Zango Bayaro, Maigunya, Barga, Kuka, Tudun Wada, Tugen Na'alma, Dan Sare, Unguwar Tofa. Kofar Fada and Dorobo while the low (weak) magnetic anomalies that are portrayed in green to blue colours were observed at Mai Kandamba, Dan Maiki, Funtua, Kankara, Malumfashi, Dan Mani, Jankollawa, Kumbawa, Dadin Kowa and Pada.

REDUCED TO THE POLE (RTP) MAP

The RTP map of the study area is displayed in Figure 6. An observed reversal in the magnetic intensity values can be seen across the study area when the RTP map is compared to the total magnetic intensity map of the area under investigation (Figure 4). On the TMI map (Figure 4), regions that were exhibiting low magnetic values are now exhibiting or having high-intensity values, and vice versa at this point. The direction of anomalies tends to be in the NE-SW and NW-SE directions. Also, anomaly intensity values range from -63.911 nT low to 66.877 nT high; the high (strong) magnetic anomalies are portrayed in red to pick colours and these colours are observed in areas around Mai Kandamba, Dan Maiki, Funtua, Kankara, Malumfashi, Dan Mani, Jankollawa, Kumbawa, Dadin Kowa and Pada, while the low (weak) magnetic anomalies are portrayed in blue to green colours and are observed in areas around Zango Bayaro, Maigunya, Barga, Kuka, Tudun Wada, Tugen Na'alma, Dan Sare, Unguwar Tofa, and both the Kofar Fada and the Dorobo.

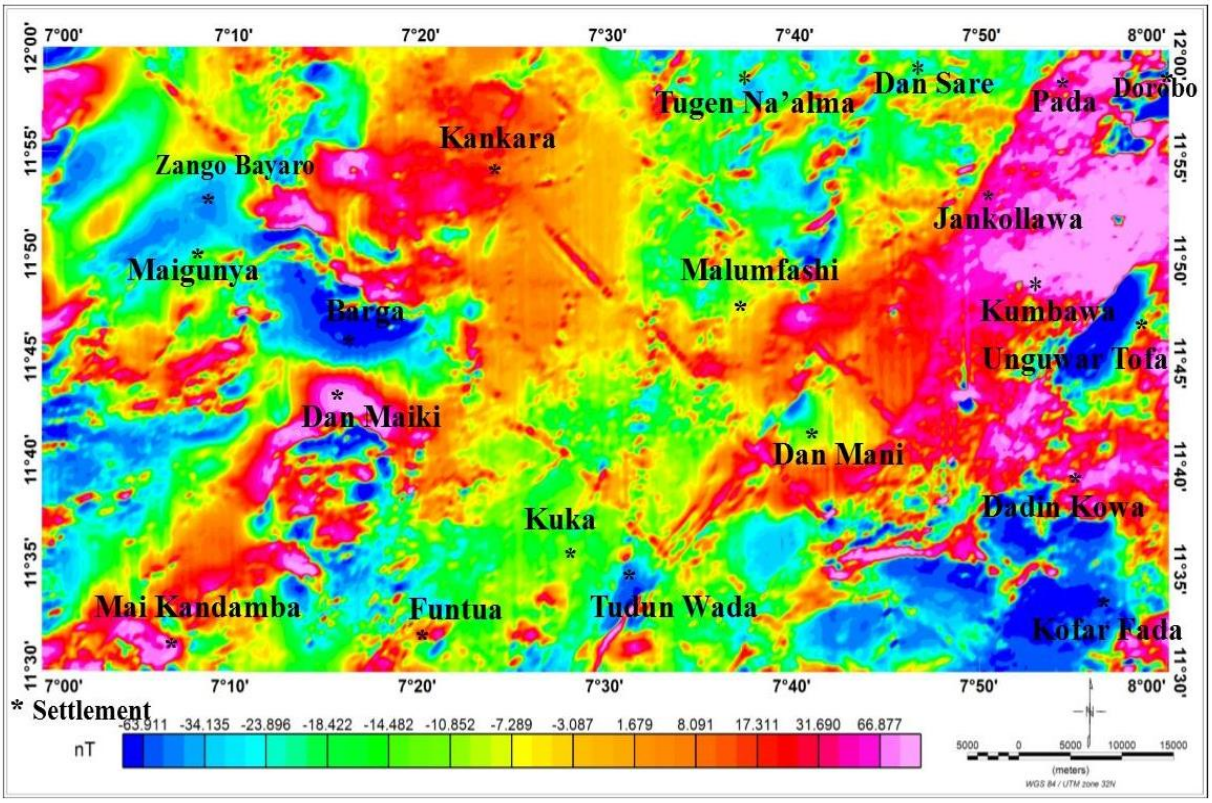

Figure 6: Reduced to Pole Map of the study area

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ANALYTIC SIGNAL MAP

The anomaly boundary or source boundary that is present within the study area is displayed on the analytic signal map (Figure 7). Additionally, it has highlighted the structural characteristics that are present within the study area. Within the scope of the investigation, the amplitude of the analytical signal ranges from 0.003 nT/m, which is low, to 0.194 nT/m, which is high or very high. Low, medium, and high are the three categories that have been assigned to the analytical signals that are contained within this zone of investigation. The amplitudes of the low analytic signal range from 0.003 nT/m to 0.035 nT/m, the medium analytic signal class ranges from 0.035 nT/m to 0.114 nT/m, and the high analytic signal values are anything that is greater than 0.114 nT/m. Structural trends that were discovered on the analytic signal map are as follows: NW-SE, NE-SW, and NNE-SSW trends.

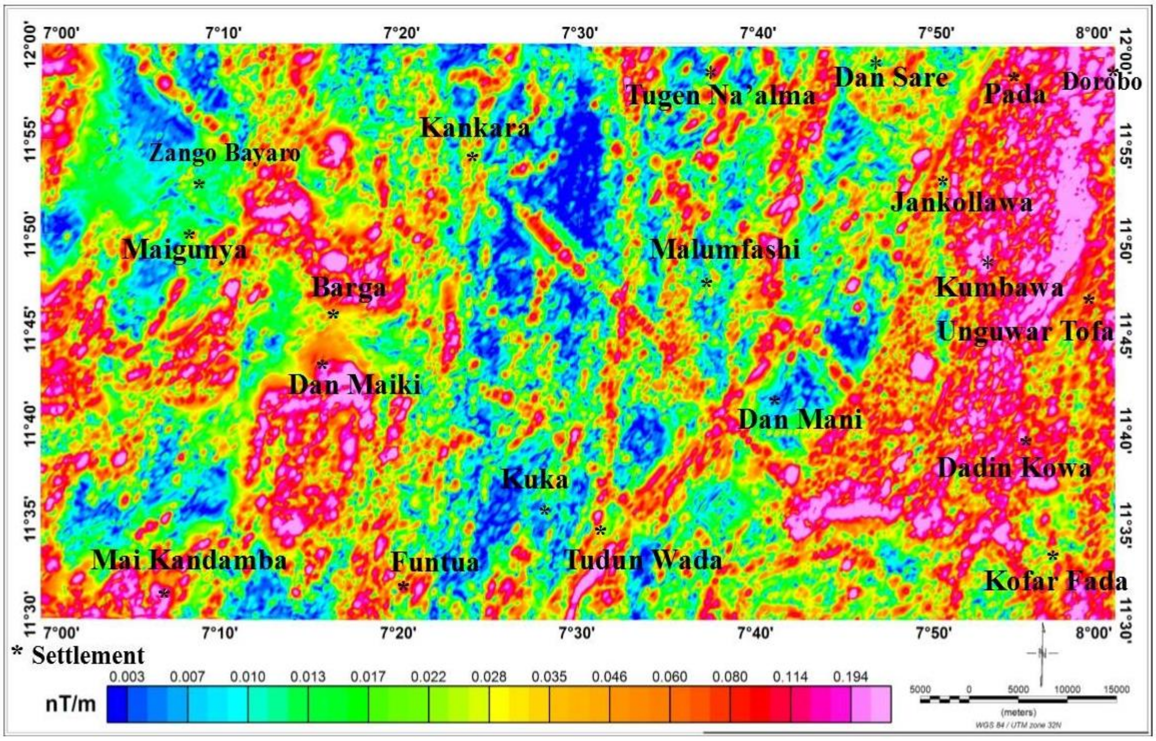

Figure 7: Analytic Signal map of the study

FIRST AND SECOND VERTICAL DERIVATIVE MAPS

Figure 8a depicts the first vertical derivative map of the area under investigation, and Figure 8b depicts the second vertical derivative map of the same area. This map, which can be seen in Figure 8a, has highlighted the short wavelengths that are present within the study area with the structures. Most parts of the map are composed of structures, beginning in the northeastern part of the map and extending down to the south along the eastern edge of the map (Figure 8a). Additionally, these structures can be seen in the western region of the area under investigation. Within the central portion of the study area, two major structures are observed to be moving in

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a direction that is from northwest to southeast. Together with the FVD map, the second vertical derivative map (Figure 8b) has brought attention to the short wavelengths that are present within the study area that are associated with the structures. This map has also shown that there is an anomalous boundary within the area that is being studied. These areas are characterized by the presence of structures, which indicates that they have the potential to be mineralization zones.

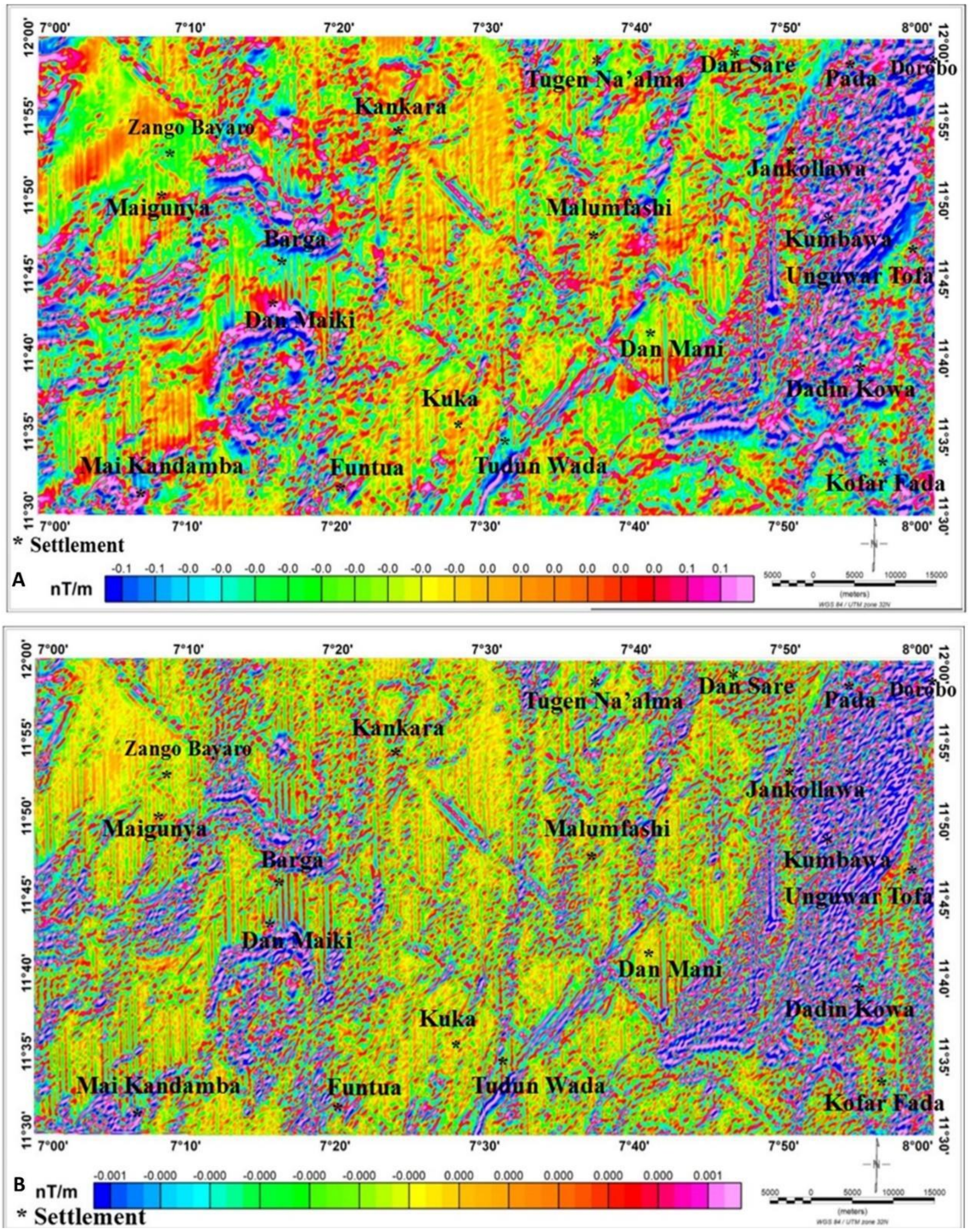

Figure 8: a. First Vertical Derivative Map, and b. Second Vertical Derivative Map

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STRUCTURAL TREND ANALYSIS OF THE AREA

Figure 9a is the first vertical derivative map of the study area compared with the structures delineated from it (Figure 9b). According to Figure 9b, most of the structures in the study area are located in the western and eastern parts of the area. Using both the FVD and the SVD, Figure 9b accurately depicts the short wavelength anomalies that have been highlighted. An examination of structural tendencies has been carried out with the help of the Rose diagram (Figure 9c). Taking into consideration the map shown in Figure 9c, we can conclude that the study area has been influenced by several tectonic activities, the structures of which are evidence of these activities (for example, the Pan-African Orogeny). Based on the rose diagram, the most prominent structural trend that has had an impact on the region is the NE-SW trend, followed by the WNE-ESE trend, the NW-SE trend, and finally the Northwest-Southwest trend. This is in agreement with the findings of other studies conducted within the Nigerian central basement complex that utilized airborne magnetic data for structural studies. These studies concluded that NW-SE and NE-SW are two of the tectonic activities that have had an impact on the Nigerian basement complex (Tawey *et al.,* 2020).

Also, structural density maps (Figure 10) have been produced to reflect the area of high magnetic structural densities. Areas showcased by the analytic signal map are areas with the highest amplitudes and also areas with the highest structural densities. Structures are conduits through which mineralization fluids find their way into host rocks and are emplaced as solid minerals. This implies that areas with very high structural densities will be viable for prospective mineral exploration. The east and west of the study area are of high lineament or structural densities as such will be areas of interest when mineral exploration is considered.

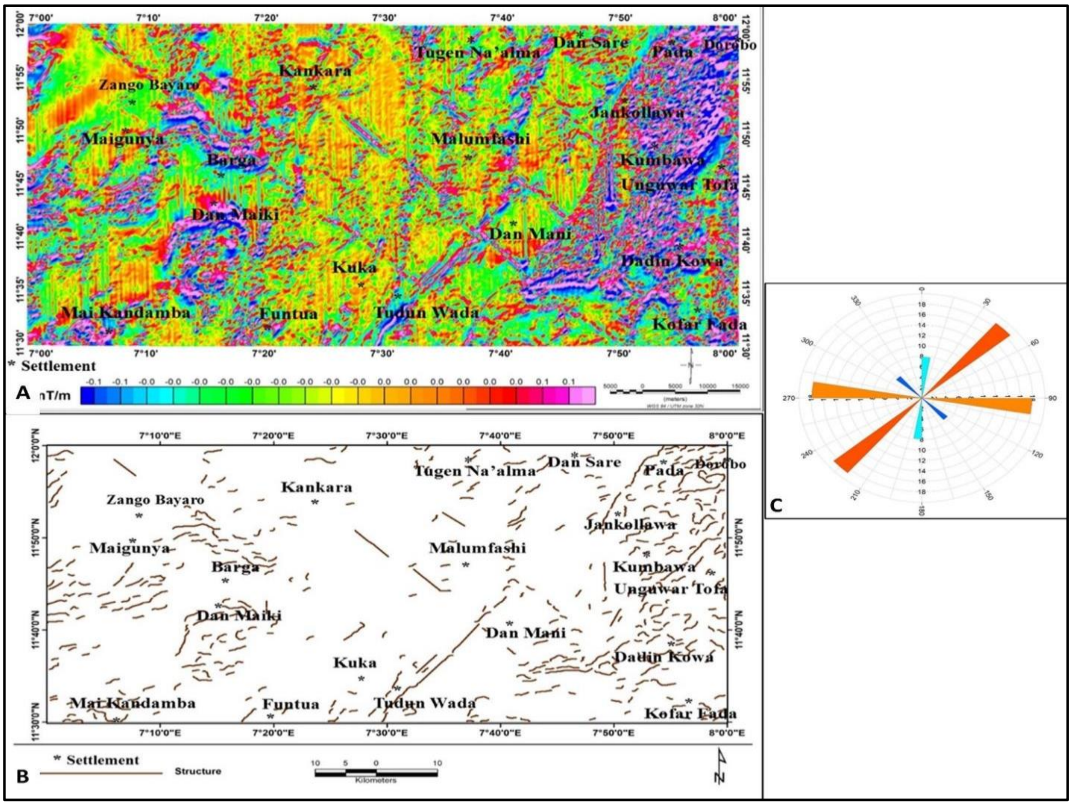

Figure 9: a. FVD map, b. structural map, and c. Ross diagram

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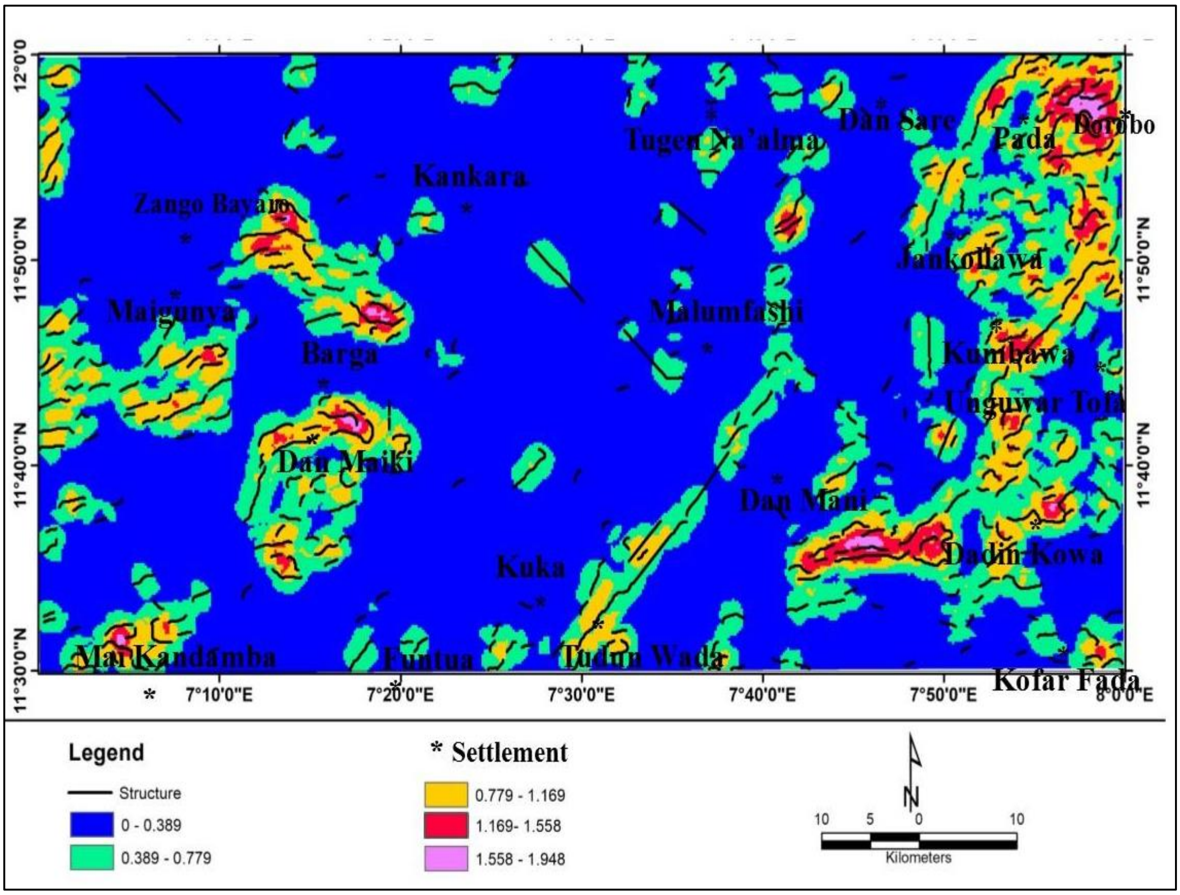

Figure 4.10: Structural density map of the study area

DEPTH TO MAGNETIC SOURCE

The depth to the magnetic source within the study area is displayed in Figure 11**,** and depths here vary from deep sources (657.99 m) to shallow sources (12.725 m). The deep depth to magnetic sources is observed around Mai Kandamba, Funtua, Kankara, Malumfashi, Dan Sare, Kumbawa, Unguwar Tofa, Pada and Dorobo, while the shallow depth to magnetic sources is around Zango Bayaro, Maigunya, Barga, Dan Maiki, Kuka, Tudun Wada, Tugen Na'alma, Dan Mani, Jankollawa, Dadin Kowa and Kofar Fada.

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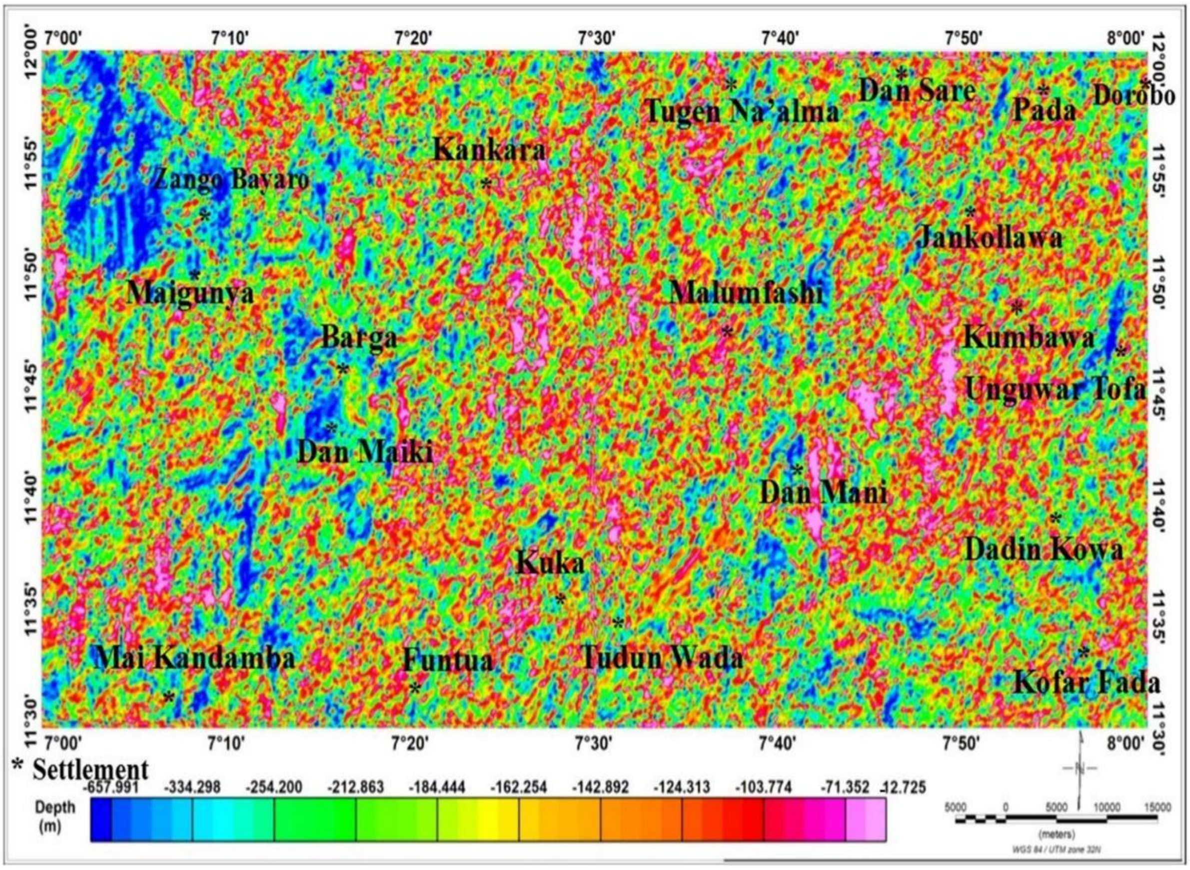

Figure 4.11: Analytic signal depths map of the study area

CONCLUSION

Vertical derivative techniques have been utilized to highlight short wavelengths with structures, primarily located in the northeastern, eastern, and western parts of the study area. These techniques resulted in the delineation of structures and the Rose diagram plotted from the delineated structures has revealed the structural trends exhibited to be in the northwest-southeast, northeast-southwest, and northeast-southwest directions. Delineation of anomaly boundaries and structural features in a study area was also accomplished using the analytic signal method. The amplitudes of the analytic signals were classified into three distinct classes: low, medium, and high. The low amplitudes ranged from 0.003 nT/m to 0.035 nT/m, while the medium amplitudes ranged from 0.035 to 0.114 nT/m. Amplitudes that were greater than 0.114 nT/m were considered high.

In addition, it has been estimated that the depth to magnetic sources within the area under investigation ranges from deep sources (657.991 meters) to shallow sources (12.725 meters respectively). From the result, it has demonstrated that Zango Bayaro, Maigunya, Barga, Dan Maiki, Kuka, Tudun Wada, Tugen Na'alma, Dan Mani, Jankollawa, Dadin Kowa, and Kofar Fada have a deep depth to magnetic sources. Particularly in the areas around Mai Kandamba, Funtua, Kankara, Malumfashi, Dan Sare, Kumbawa, Unguwar Tofa, Pada, and Dorobo are the regions that contain shallow depth to magnetic sources.

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