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MAGNETIC LINEAMENTS AND BASEMENTS INTERPRETED FROM HIGH-RESOLUTION AEROMAGNETIC DATA UNDERNEATH LOWER PART OF BENUE TROUGH, NIGERIA

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ABSTRACT
The high-resolution aeromagnetic data of part of Benue trough has been used for the interpretation of magnetic lineaments and basements for exploration of economic minerals in the region. We used the vertical derivative filters as the techniques for the interpretation of magnetic lineaments. Lineament analysis of the aeromagnetic data demonstrated four tectonic trends in the area. The lineaments are in the northeast to southwest (NE–SW), east, northeast to west, southwest (ENE – WSW), north to south (N – S), and east to west (E–W) directions. The NE – SW and ENE–WSW are the most dominant whereas the N–S and E–W are the minor trends. By implication, we see that the interpreted lineaments has link with the orientation of the trough and directions of major thermo-tectonic activity in the region. The total grid map of the TMI of the area was made into 25 blocks of 50 x 50 km with 50 % overlap where 25 power spectrum were generated for the depth estimations using spectral analysis. We have estimated different values of magnetic basement between 2 km and 5 km and the shallow magnetic sources (depth to top of intrusions) vary between 0.24 km and 1.20 km. In many blocks, the estimate of the shallow depth to magnetic sources were rejected on the basis that in those blocks, either there are insufficient observation data points (at least three) or no local maxima were obtained for the estimation of depth to top of magnetic sources. This could suggest the complex tectonic nature of the region.

Keywords: Benue trough; High-aeromagnetic data; magnetic lineaments; vertical derivatives.

INTRODUCTION

Qualitative analysis of high-resolution of aeromagnetic data offers an effective and resourceful geophysical implement for geological mapping and interpretation of magnetic lineaments around the globe. High values of magnetic anomaly are customarily observed over basement or igneous rock areas in contrast to the low values in most sedimentary rocks since sedimentary rocks have less magnetic intensity values when compared to the magnetic intensity from basement or igneous rocks (Ali *et al.*, 2014; Essa & Elhussein, 2017; Abdullahi *et al.*, 2019a). The idea of spectral analysis by Spector & Grant (1970), is a well-known quantitative geophysical technique for the estimation of magnetic basement from radially averaged power spectrum method (Abdullahi *et al.*, 2019b). According to Abdullahi *et al.* (2019b), the logarithm of the power spectrum generated from horizontal distribution of magnetic sources is always directly proportional to $(-2dw)$, where d is the depth to top of the magnetic sources and w is the radial wavenumber. The depth of the magnetic sources can therefore be estimated directly from the slope of the logarithmic plot of the power spectrum against the wavenumber. The power spectrum of magnetic sources could suggest the presence of various horizontal distributions of magnetic sources in the crust pending on the number of segments on the power spectrum. The power spectrum is usually not straight due to the randomly and uncorrelated distribution of magnetic sources assumed in the Spector and Grant (1970) method.

In the present work, we used the vertical derivative filters and derived the magnetic lineaments in the study area. In addition to the magnetic lineaments in the area, the methods also illustrated zones of volcanic activities. Magnetic basement estimations were carried out using the spectral analysis. The interpretation of 25 different power spectrum generated from the total grid indicated complex tectonic nature of the region.

Geology and tectonics settings of the study area

The geology and sequence of events of sedimentary evolution of the Nigerian Benue trough has been well investigated and published by authors (Abdullahi & Singh, 2018; Abdullahi *et al.*, 2019a, b). The study area (Lower Benue trough) is underlain by deposited sequence of Cretaceous sedimentary rocks. Figure 1 shows the geological map with tectonic events in the study area with the Cretaceous formations from the Asu River group up to the Nsukka formation been in order of their decreasing ages. The Precambrian basement complex is made up of essentially, the granitic and magmatic rocks as can be seen from the eastern and the south-eastern margin of the map (Abdullahi *et al.*, 2019a, b).

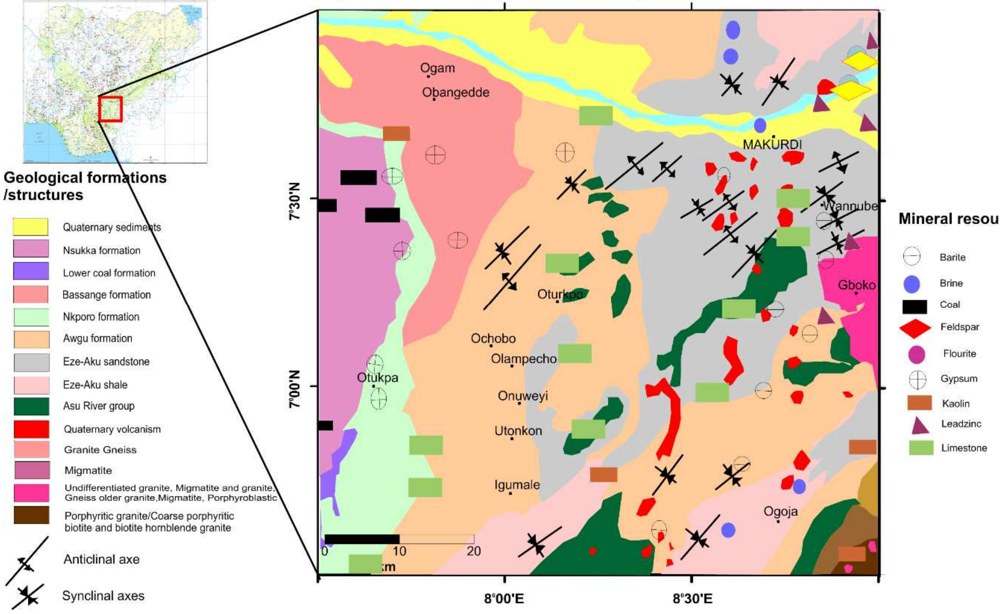

Figure 1. Geological map superimposed with the anticlinal and synclinal axes and mineralization in the area (Modified after Abdullahi *et al.*, 2019a, b).

The Asu River group formed the oldest Cretaceous sediment in the region. It consists of shale and limestone with intercalations of sandstone. The shales have been highly fractured and are fissile in nature (Abdullahi *et al.*, 2019a, b). The Eze-Aku shale consists of black shale, siltstone and sandstones whereas the Eze-Aku sandstone consists mainly of sandstones. Awgu formation is made up of shale and limestone of Coniacian age. The Awgu formation is overlain by Nkporo formation of mainly shale and mudstone. Bassange formation consists of sandstones and ironstones, whereas the lower coal formation consists of coal, sandstones and shales. Nsukka formation is made up of false-bedded sandstone of Campanian age (Abdullahi *et al.*, 2019a, b).

The sediments are strongly affected by the intense compressional folding that occurred during the mid-Santonian tectonic episode leading to the production of the hundreds of anticlines and synclines in the Benue trough (Abdullahi *et al.*, 2019a). This development is in connection to the complete orogenic cycle (sedimentation, magmatism, metamorphism and compressive tectonics), which resulted to the numerous intrusive (mainly basalts) invaded the Awgu shale, Eze-Aku group and Asu River group (Abdullahi & Kumar, 2020). The Eze-Aku sandstone and the Albian Asu River shale are major host of lead–zinc, barite and fluorite and other metalliferous mineral deposits (Abdullahi *et al.*, 2019a, b).

Aeromagnetic data and vertical derivatives analysis

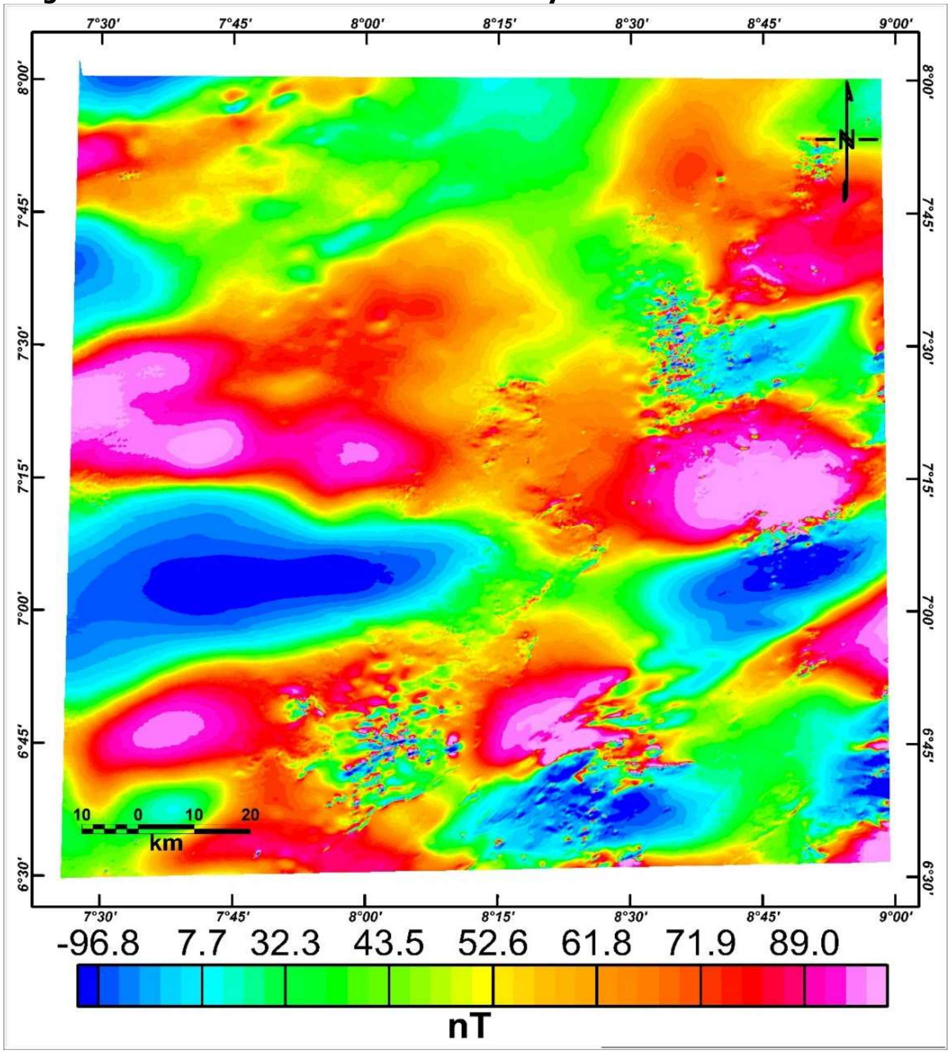

Figure 2. Shows High-resolution aeromagnetic anomaly (TMI) map of the study area.

Figure 2, shows the total aeromagnetic intensity (TMI) anomaly map of the area. The dataset presented has been used for the interpretation of magnetic basement using scaling spectra method by Abdullahi *et al*. (2019b) and also for the estimation of Curie depth using centroid method by Abdullahi & Kumar (2020). The high magnetic values interpreted shallow basements and regions of volcanic intrusions whereas the low magnetic values interpreted deeper crust as well as sedimentary basins in the area of study (Abdullahi *et al*., 2019b; Abdullahi & Kumar, 2020).

The vertical derivative of magnetic field in the vertical direction defined what is referred to as the vertical derivatives. These derivatives emphasis the local anomalies by enhancing the high frequency (or short-wavelength) anomalies and suppresses the low frequency (or long-wavelength) anomalies in the magnetic field data (Verduzco *et al*., 2004). Figure 3 shows the first vertical derivative (FVD) map of the TMI anomaly of the study area. The zones of very high magnetic anomalies evidenced on the map could be linked with the volcanic intrusions and the associated minerals in the area (barite; kaolin; limestone; lead-zinc).

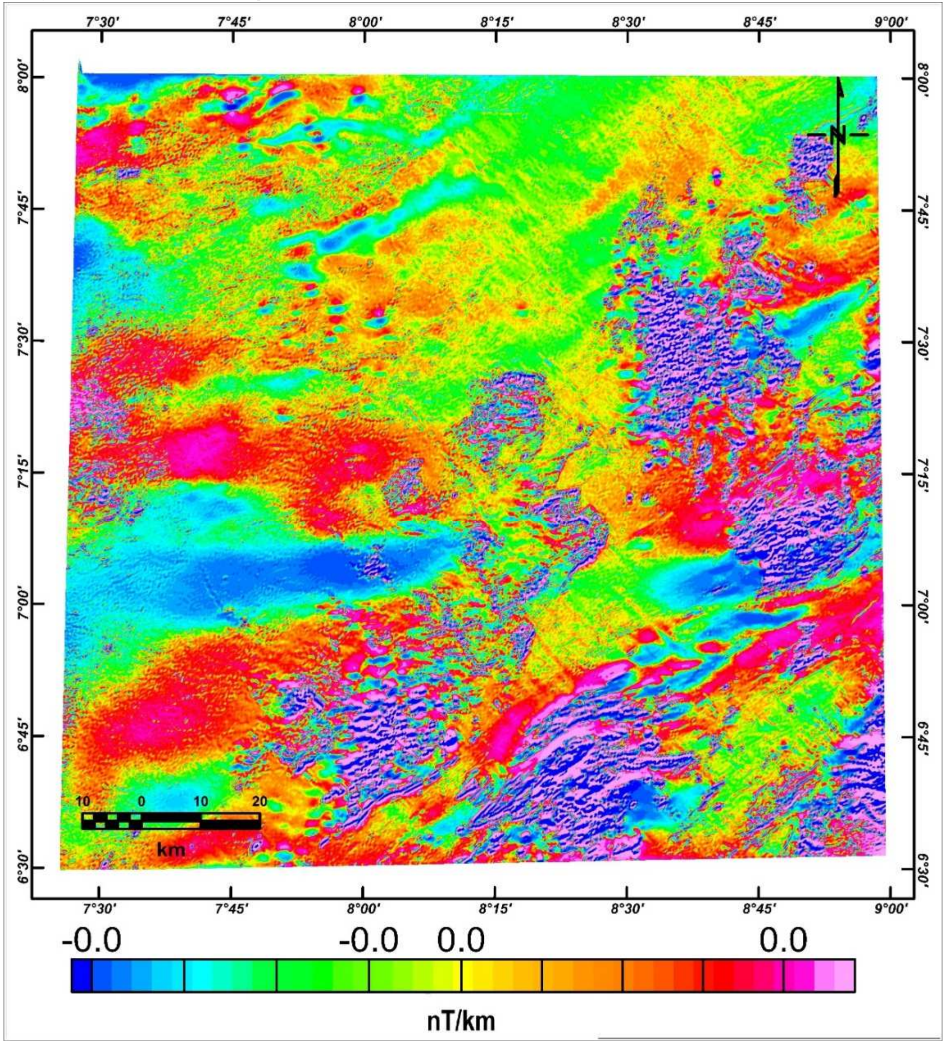

Figure 3. The calculated First Vertical Derivative (FVD) of the TMI grid. Short wavelength anomalies are seen enhanced to interpret near surface geology.

Second Vertical Derivative (SVD) map of the TMI of the area has also been calculated (Figure 4). As the FVD-TMI map interprets the same volcanic intrusions that are associated with the minerals found in the area though it has smoother surface texture. The SVD-TMI shows more emphases on the local anomalies and attenuated the signal due to the deeper features.

Magnetic lineament analysis was carried out on the FVD map. This was done by observing the trends and amplitudes of the anomalies that matches the geological history of the region. Figures 5 & 6 shows the interpreted magnetic lineaments derived from the aeromagnetic data. The plotted rose diagram of the interpreted magnetic lineaments shows the dominant of NE-SW and ENE-WSW trends and the minor of E-W and N-S trends. The lineaments could be interpreted as the edges of geological bodies and directions of structures which might have been in connection with the thermo-tectonic events and the evolution of the sedimentary basins in the region.

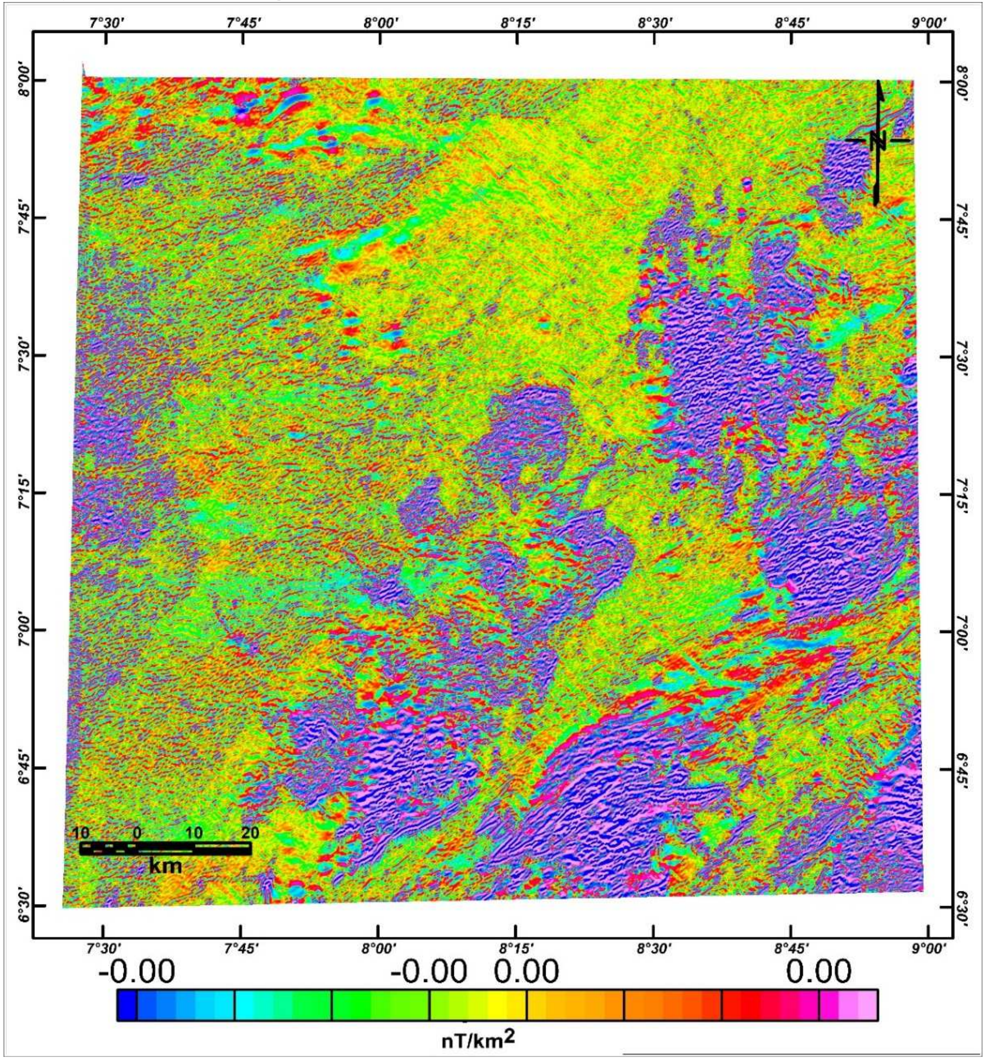

Figure 4. The calculated Second Vertical Derivative (SVD) of the TMI grid. Short wavelength anomalies are seen enhanced to interpret near surface geology and the long wavelength anomalies been supressed.

RESULTS AND DISCUSSION

Analysis of the high-resolution aeromagnetic data of the present study area in relation to the geological information could be interpreted that, the high magnetic anomalies observed in the area correlated to zones of volcanic intrusions.

SVD map (Figure 3) TMI of the area shows more emphases on the local anomalies and attenuated the signal due to the deeper features. On the map, we have also demarcated areas of volcanic intrusions and the associated minerals as in the case of the FVD – TM/I (Figure 4). Magnetic lineament analysis is carried out. This is done by observing the trends and amplitudes of the anomalies that matches the geological history of the region. The present study, reported prominent NE–SW and ENE–WSW trends /and the subordinating E– W and N–S trends. The lineaments could be interpreted as the edges of geological bodies and directions of structures which might have been in connection with the thermo-tectonic events and the evolution of the sedimentary basins in the region.

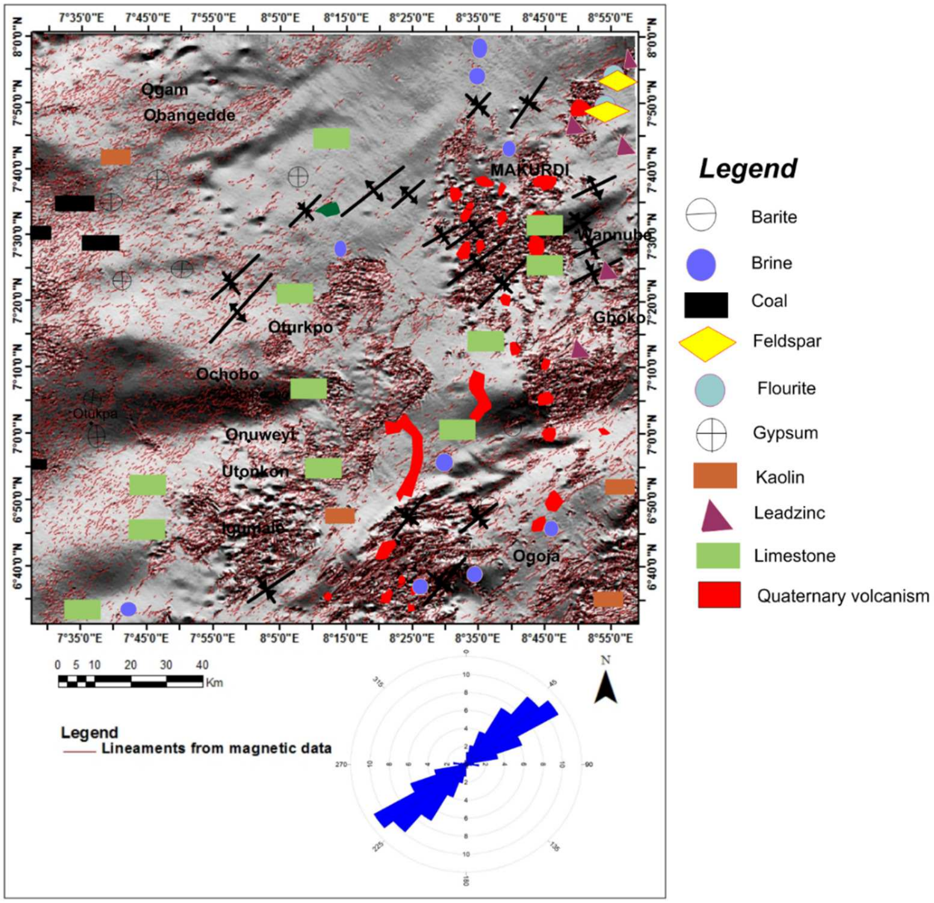

Figure 5. Interpreted magnetic lineament superimposed with the anticlinal and synclinal structures and the different minerals on the FVD grid map of the area.

The dominant NE–SW trends were observed in other studies around the north–south and eastern part of this area as reported by (Abdullahi *et al*., 2019a). The NE–SW trends are interpreted to correlate with the deep seated faults, which may have been reactivated by NE– SW sinistral shear during the opening of the trough. The observed NE-SW trends represent the trending Neoproterozoic tectonic units of the Brasiliano/Pan-African orogen which has been parallel to the orientation of the Benue trough and it is assumed to control the dextral shear zones of the late Pan-African age supporting the findings of Abdullahi *et al*. (2019a). The ENE–WSE trends were also observed and delineated in (Abdullahi *et al*., 2019a). The trends represent the mega shear zones in Africa called the Central African Shear Zone (CASZ), which resulted from the important tectonic movements that occurred during the Pan-African orogenic cycle. The ENE–WSW is also a dextral shear zone that is related to the wider mylonite belts pre-dating at the Cretaceous times, the opening of the South Atlantic Ocean. The N–S lineaments are minor trends. In the lower and middle parts of Benue trough the delineated N–S lineaments, suggest the minor trends in the area. Their formation may be associated to either the migration of the African plate over the mantle plume or shear movements along the pre-existing ENE–WSW faults in the Pan-African basement (Abdullahi *et al*., 2019a).

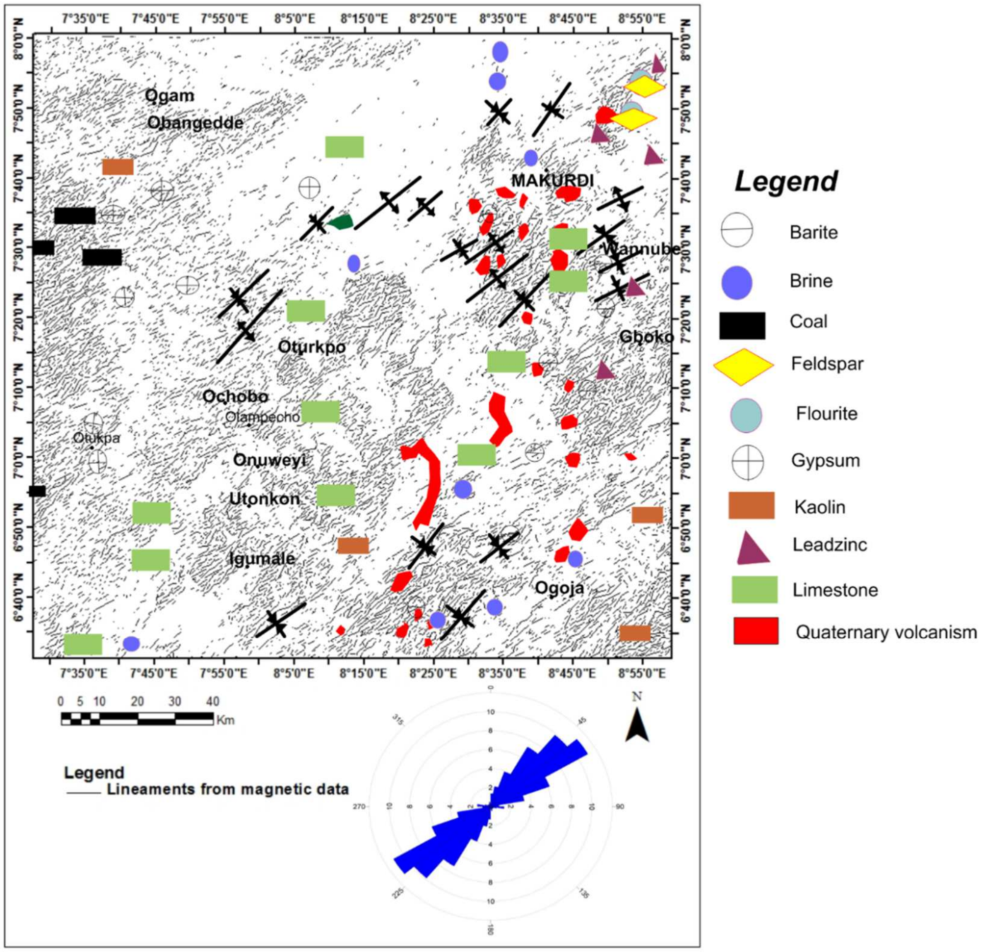

Figure 6. Interpreted magnetic lineament superimposed with the anticlinal and synclinal structures and the different minerals found in the area.

For the magnetic basement estimations using spectral analysis, we have divided the TMI grid into 25 sub-grids (blocks) of 50×50 km with 50% overlap (Figure 7). Each grid is processed to remove the first order trend based on edge points using 10% square maximum entropy expansion. Therefore, we calculated the basement of magnetic sources between 2 km and 5 km (Table 1). The shallow depth values vary between 0.24 km and 1.20 km. These depths are scattered and could be interpreted as the depth to top of intrusions at various location. Figure 8 presents the result of the calculated magnetic basement (deeper magnetic sources) in the region.

In the study area, we present dominant magnetic basement of 4 km. These are observed in the areas of Igumale, Makurdi, Ogoja, Otukpa and Oturkpo. Maximum depths of 5 km are observed in the areas of Gboko and Wannube whereas the minimum depths of 2 km are observed around Obangedde and Ogam with the intermediate depths of 3 km calculated around Ochobo and Olampecho areas.

Previous studies in the region suggested of depth of sedimentary cover of 5 – 7 km around Igumale (Abdullahi *et al*., 2019b). Around Makurdi, depths of 5 – 6 km (Ajayi & Ajakaiye, 1981; Abdullahi *et al*., 2019b). At Ogoja axis, depth range of 1 – 4 km are calculated (Ofoegbu & Onuoha, 1991; Abdullahi *et al*., 2019b). Along Gboko – Wannube axis, depths of 2 -9 km were reported (Ajayi & Ajakaiye, 1981; Abdullahi *et al*., 2019b). These mentioned results of estimated sedimentary cover in region showed good correlation with our presented result and in addition, we presented a more detailed depths to magnetic sources corresponding to magnetic basements and depths to top of igneous intrusions in the region. Analysis of the high-resolution aeromagnetic data of the present study area in relation to the geological information, could be interpreted that, the high magnetic anomalies observed in the area correlated to zones of volcanic intrusions. The intrusions (at various depth) appeared to spread over almost 70–75% of the area beyond their exposure on the geological map.

The intrusions invaded the Cretaceous sedimentary rocks and could also be found within the basement rocks. The intrusions could be the contributing factor to the positive gravity anomaly observed in the area (Ajayi and Ajakaiye, 1981; Abdullahi and Singh, 2018).

The magnetic lineaments interpreted could be termed as geomorphic lineaments since they can be related to the fracture zones, the Pan – African continental shear zones and the imprint igneous intrusions in the region (Anudu *et al*., 2014). The presence of the magnetic lineaments and their concentration over the zones of igneous intrusions could be an indication that the region is very complex tectonically associated with weak magnetic basement at different depths (Abdullahi & Kumar, 2021). It may have provided suitable hosts for different kinds of economic mineralization such as barite, cadmium, coal, copper, gypsum, lead, silver, and zinc in the region (Abdullahi *et al*., 2019a). The identified and mapped lineaments are closely associated with the general trends of geological structures of the Pan-African plate which predated the compressional folds and faults within the Cretaceous sediments and strike-slip movements during the separation of Africa and South America (Abdullahi & Kumar, 2021).

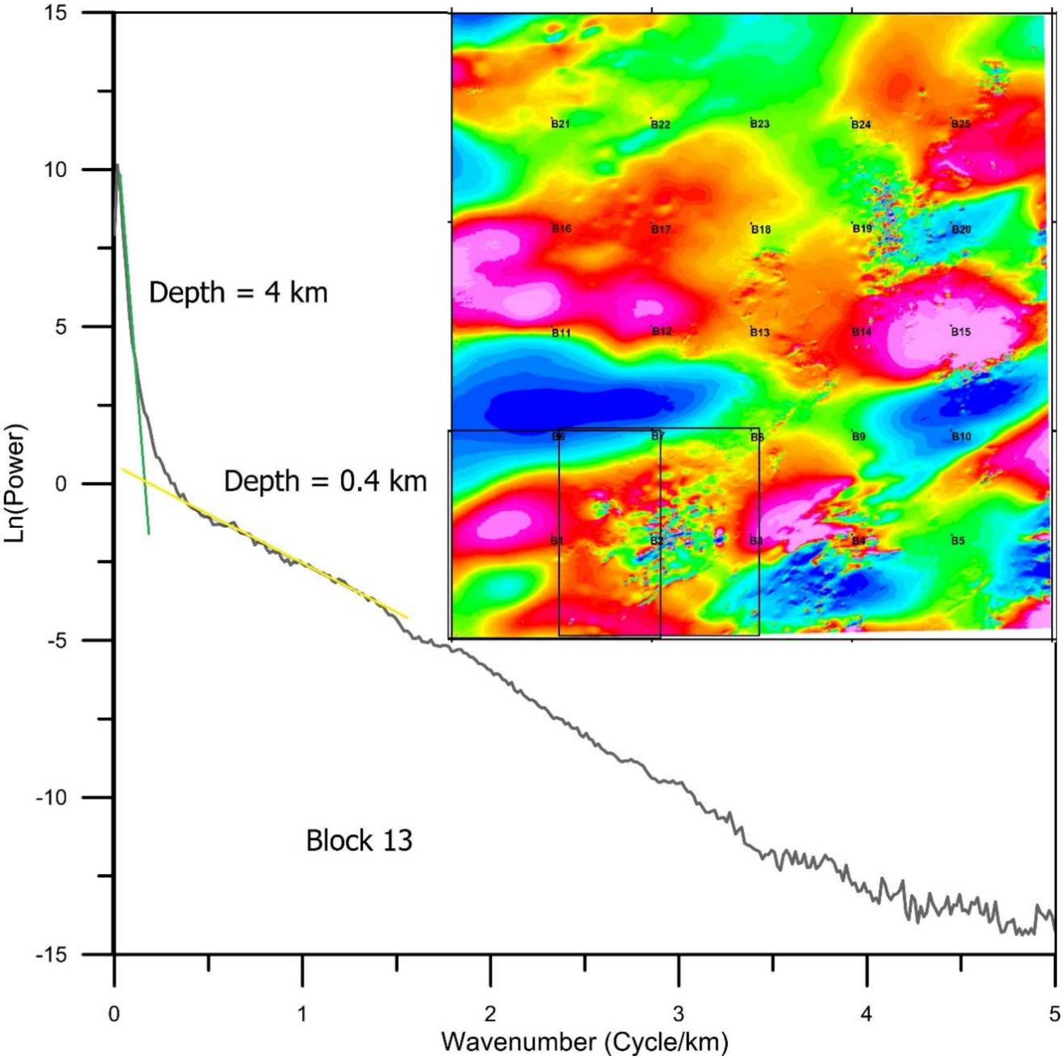

Figure 7. The power spectrum of block 13, for depth estimation to top of magnetic sources.

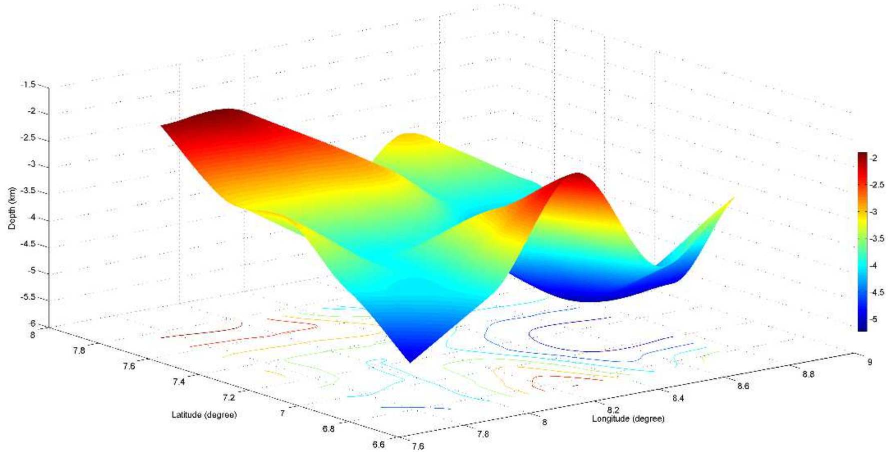

Figure 8. 3-D result plot of magnetic basement (2 -5 km) from spectral analysis.

Table 1*. Result of estimated magnetic basement*

Block No.	Deeper magnetic sources (km)	Shallow magnetic sources (km)
B1	5	0.79
B2	4	0.30
B3	2	0.33
B4	4	0.65
B5	5	-
B6	4	-
B7	4	-
B8	3	0.29
B9	5	0.85
B10	5	0.28
B11	3	-
B12	4	0.24
B13	4	0.40
B14	5	0.28
B15	5	0.27
B16	3	0.78
B17	3	-
B18	3	0.82
B19	4	0.66
B20	4	-
B21	2	0.32
B22	2	-
B23	4	1.20
B24	3	0.34
B25	4	-

CONCLUSION

Analysis of high-resolution aeromagnetic anomaly over the lower Benue trough for the interpretation of magnetic lineaments, distributions of magnetic sources as well as magnetic basements have been carried out and yielded the following conclusions;

- Vertical derivative filters have been a convenient and time saving techniques for mapping of magnetic lineaments as well as igneous activity in this region.
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- The mineralization in the area is related to the volcanic rocks that intruded the Cretaceous sedimentary rocks in the region.
- The interpreted lineaments and igneous volcanic zones are indications of the fact that the region is complex tectonically.
- The interpreted lineaments may have provided suitable hosts for different kinds of economic mineralization such as barite, cadmium, coal, copper, gypsum, lead, silver, and zinc in the region.

- Magnetic basement between 2 km and 5 km with shallow depth to top of magnetic sources between 0.24 km and 1.20 km are calculated and interpreted in the study area.

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