Available online at www.worldnewsnaturalsciences.com

World News of Natural Sciences

An International Scientific Journal

WNOFNS 45 (2022) 58-92 EISSN 2543-5426

Application of aeromagnetic in determination of lineament of Hawal basement complex Northeast Nigeria

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ABSTRACT

Lineament study over Hawal Basement Complex has not been fully mapped out for mineral exploration to generate revenue and employment. The study which was carried out using upward continuation filter, first and second vertical derivative filter, analytical signal filter, and Euler deconvolution filter were interpreted. It shows that the Basement Complex has high magnetic intensities with multiple fault lines, and three major trend directions of lineament NE-SW, NW-SE, and E-W respectively. The analytical signal filter gives additional evidence that there is tectonic control on the emplacement of these basic rocks (Younger basalt and Basalt). Their emplacement utilized pre-existing fractures or lineaments in the Precambrian Basement Complex and correlate with major river courses/foliation trends. These fault zones discovered around areas like Meringa, Biu, Shaffa, Shani, Song, and environs may serve as hosts for mineral exploration.

***Keywords*:** Magnetic, Filter, Mineral, Derivative, Hawal basement complex, aeromagnetic, Nigeria

(Received 18 September 2022; Accepted 11 October 2022; Date of Publication 12 October 2022)

1. INTRODUCTION

The mineral potential and major lineaments trend in the Hawal Basement Complex is yet to be fully mapped out, the area lies within lies between longitudes 12° 00’ and 13° 00’ E, and latitudes 9° 30’to 11° 00’N (Fig. 1). The basement stretches into the adjoining Republic of Cameroun. It is no doubt that the economic potential of this complex cannot be ruled out due to diverse minerals deposits accruing to this area, which has not been judiciously tapped to enhanced a decline in the poverty rate or degree of unemployment of mostly the youth of the Country. The overwhelming majority of economically significant mineral resources are found beneath the earth's surface, and to use them, knowledge of their presence must first be confirmed. This knowledge will give relevant information about mineralization and tectonic activities.

The process of mineralization results in a lineament-mineral association . Lineaments are significant lines of landscapes that reveal the hidden architecture of the rock basement. Fracturing/faulting or structurally regulated topographic lines produce rectilinear features known as lineaments. They are, in reality, lines from the earth's "Physiognomy" (Geological Survey of Nigeria, (2006), Christopher and Alaga, (2016). Lineament maps are invaluable tools for (i) Foundation and civil engineering constructions. (ii) Identifying prospective oil-gas/minerals/water accumulation zones. (iii) Earthquakes and natural hazards monitoring. Detailed Studies on geologic lineaments have shown that there is a close relationship between groundwater flow and yield. Cratchley and Jones, (1965); (Abubakar (2014) were among the first to conduct a gravity survey in the upper and middle Benue Trough. They showed that the ~~Bouguer is gals~~ are generally parallel or sub-parallel to the margins of the trough.

A positive regional anomaly with an amplitude of approximately 50 mGal and a mean width of more than 150 km was identified, interpreted as indicating a thinner crust beneath the basin than the flanking basements; and shorter-wavelength residual anomalies, consisting of an axial positive anomaly surrounded on both sides by negative anomalies, regarded as suggesting an axial zone of shallow basement rocks containing basic to intermediate intrusive flanked by zones where the sedimentary infill reaches a thickness of up to 6 km. Bassey et al. (2012) conducted a study in the Hawal Basement Complex of the Hawal Area, northeast Nigeria, on digital filtering of aeromagnetic maps for lineaments detection. They found several basement faults, some of which were previously unknown or unmapped, and which are linked to key petro-tectonic features such as Nigeria's North Central crystalline shield, the Nupe Basin, the Benue Trough, the Chad Basin, and certain Equatorial Atlantic fracture zones.

They concluded that these basement faults exercise control on the emplacement of intrusive bodies in the area and the flow direction of major rivers NE-SW. Onuba et al., (2012), also noted from a composite magnetic map of some parts of Upper Benue Trough and southern Chad Basin, Nigeria complied from aeromagnetic maps highlighted a prominent NE–SW magnetic low in the area.

The large NE–SW anomaly is most likely generated by intra basement intrusion with high magnetic susceptibility at depths ranging from 0.67 to 2.27 kilometers, according to magnetic depth estimates and three selected profiles across the anomalies using spectral analysis.

The sedimentary area cover of roughly 2.27 km has been marked by these sediments, according to two-dimensional modeling of the profile. The existence of a mafic igneous intrusion, which may have occurred in some part of the study area before being buried by trough sediments, indicates that deep fissures exist in the crust beneath the trough, supporting the theory that the trough is a rift structure. Maxwell et al., (2012), carried out aeromagnetic data interpretation of Triple junction area of the Upper Benue Trough, the study revealed NE – SW trending of lineament which correlate with the geology of the area showing that the Benue Trough trends NE – SW, indicating that they have some structure control. The study also revealed NE – SW structure as the youngest in the Nigeria Basement. Fault and foliation have been used to account for the principal lineaments seen. The lineaments extend over Niger, Chad, and Cameroon. Induced magnetization in the area is responsible for the crustal rocks' anomalous magnetic field.

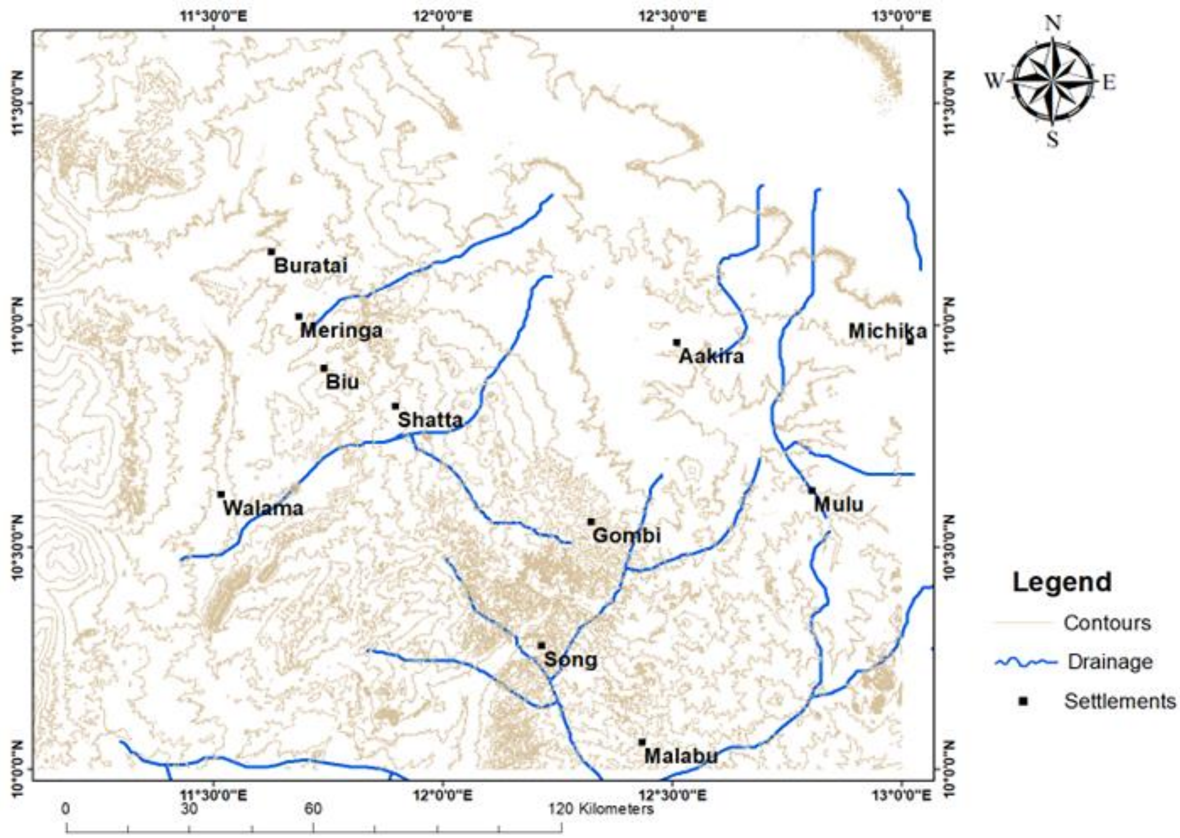

Fig. 1. Topography map of the study area.

Some parts of the anomalous field may contain a significant amount of leftover magnetism. High–sensitivity aeromagnetic data across an area containing both low–amplitude, linear anomalies caused by structurally deformed magnetized layers towards the top of the sedimentary section and high–amplitude wide anomalies caused by these two source areas. From the above, one thing that is not controversial in the trough and the Basement Complex is its great potential for sources of mineral and raw materials of economic significance. According to Obaje, (2009), the area comprises of economic importance resources such as limestone, bricks and fire clays, construction stone, laterite, and coal, some of which are being exploited. He also noted that the trough has considerable occurrences of base metal sulphide (lead with a little quantity of copper), cadmium, silver, and related mineral barites.

The application of analytic signals, upward continuation, and first vertical derivatives to the research area's aeromagnetic data is intended to shed further light on the area's mineral potential, lineament, and tectonic setting. The exploration of these minerals will lead to the generation of revenue for the nation and employment for the citizens. This research is aimed at studying and delineating the lineament of the Hawal basement complex in Northeast Nigeria using Aeromagnetic data.

2. GEOLOGY OF STUDY AREA

Approximately half of Nigeria is subjected to the Basement Complex. It stretches westward into Dahomey and the Benin Republic, and eastward into the Cameroons (Zaborski, 1998). The Basement Complex is covered with Cretaceous and younger sediments in the remaining half of the country. It is part of the Hawal massif, a Precambrian basement complex in northeast Nigeria that covers an area of 18,562 km^2.

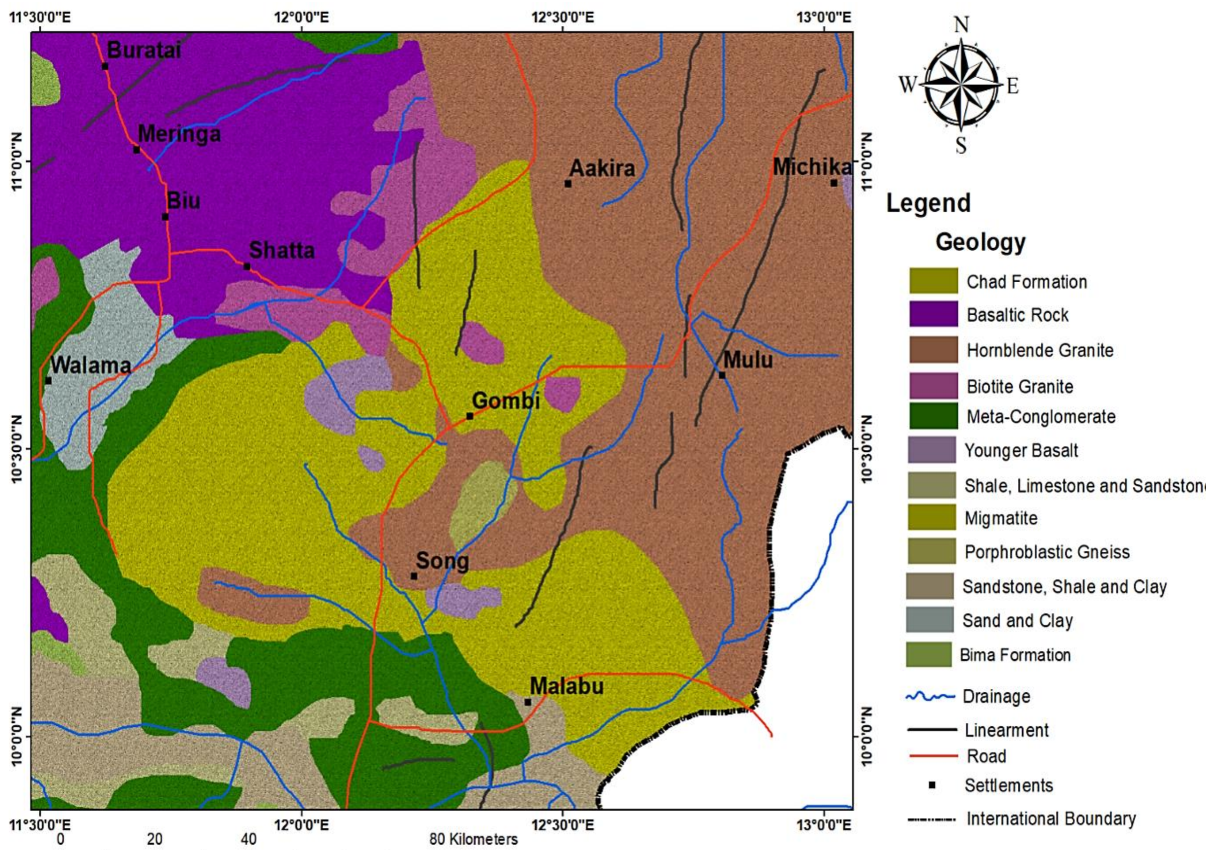

Fig. 2. Geological Map of Hawal Basement.

This massif is bordered on the south by the Cretaceous E-W trending arm of the Benue Trough (Yola Rift), and on the west by the Cretaceous N-trending arm of the Benue Trough (Yola Rift) (Gongola Basin). It is bordered to the north by the Quarternary Chad Basin.

The Nigeria Basement Complex is believed to be mostly Precambrian in age (Zaborski, 1998). It does, however, more likely contain Paleozoic intrusions (Oyawoye, 1964). Falconer, (1911) was the first to investigate the basement Complex, recognizing the age difference between the Precambrian Older Granites and the Jurassic "Younger" Granites of the Jos plateau (Ohi, 2020). Northern Nigeria is underlain by Precambrian gneisses, migmatites, and metasediments that have been intruded by a succession of granitic rocks, which are represented by a series of Older Metasediments and gneisses that are believed to be Birrimian in age and older. These rocks have undergone a variety of metamorphic cycles, resulting in the majority of them being transformed into migmatites and granite-gneiss (Bassey and Unachukwu, 2019). During the Pan African orogeny, younger meta-sediments, thought to be Upper Proterozoic in age, were deposited on this granitised basement and folded with it. They have a low metamorphic grade and are today found in North-West Nigeria as synclinal troughs among older rocks. The Older Granites are a succession of basic, moderate, and acid plutonic rocks that penetrate both the basement rocks and the newer supracrustal layer.The area's youngest rocks are part of a sequence of volcanic rocks that were intruded into Older Granite strata during epeirogenic uplift during the Pan-Africa Orogeny in the Lower Palaeozoic (Kogbe, 1989). The area's rocks were included on the Nigeria Geological Survey Agency's 2006 edition of the geological map of Nigeria (NGSA). This was modified in Fig. 2. The area of study comprises of two parts, majorly the basement and little sedimentary basin at the boundary of the northern and southwestern portions. The migmatite, which is found in the central part of the study area, is the most common rock type; others include basalt, biotite granite, prophyritic hornblend granite, meta-conglomerate, prophroblastic gneiss, and younger basalt, as well as sedimentary rocks such as sandstone, shale, clay, and limestone.

3. MATERIALS AND METHODS

The data set that was used for this study covers 6 digitized aeromagnetic sheets with sheet numbers 133 (Biu), 134 (Chibok), 154 (Shani), 155 (Garkida), 175 (Shellem), and 176 (Zummo) which were obtained from NGSA produced between 1974 and 1980. The total area covered for this study is 18,150 km^2. On a scale of 1:100,000, the data are presented as ½ by ½ aeromagnetic sheets. For easier reference, these maps were numbered and the names of the places each map covers were printed on them. A total of 340 maps cover the entire country. All the parts of Nigeria have been covered; the study area covered parts of the Upper Benue Trough, adjoining Chad Basin, and the Adamawa highland or Hawal Massif. The six digitized maps were combined to form the composite data of the study region to obtain a single aeromagnetic map of the study area. The dataset was processed using a computer program.

3. 1. Regional –Residual Separation of the Total Magnetic Intensity (TMI)

Two important disturbances can be observed on the picture that emerged from a composite magnetic map, which is different in order of sizes, are generally superimposed. The regional-residual separation techniques used for this study are based on the Robust Polynomial Fitting method. The magnetic field generated by all subsurface sources is combined in geophysical surveys to produce magnetic data. To distinguish between anomalies resulting from local, near-surface masses and those originating from larger and deeper features, the words "residual" and "regional" were adopted.

3. 2. Euler Deconvolution

Based on both their amplitudes and gradients, Euler deconvolution was utilized to locate the cause of a potential field anomaly. Euler's equation can be shown in equation 1 when using magnetic field data:

$$\frac{(x-x_o)\partial T}{\partial x} + \frac{(y-y_o)\partial T}{\partial y} + \frac{(z-z_o)\partial T}{\partial z} = N(B-T) \qquad (1)$$

as proposed by Ademakinwa et al., (2020)
where (x_0, y_0, z_0) denotes the location of a magnetic source with a total field T of (x, y, z). The field as a whole has a B regional value. The degree of homogeneity, N, can be translated into a structural index (SI), which is a determinant of a potential field's rate of change with distance.

3. 3. Analytic Signal Technique

To pinpoint the specific location of the causative body, this technique was utilized to filter the magnetic data, which simplified the positive and negative peaks often associated with magnetic bodies. The amplitude of the three-dimensional analytic signal at position (x, y) can be obtained from the three orthogonal gradients of the magnetic field using the expression given by equation 2 according to Roest and Pilkington (1992); Alhussein et al., (2014).

$$|A(x,y)| = \left(\left[\frac{\partial T}{\partial x}\right]^2 + \left[\frac{\partial T}{\partial y}\right]^2 + \left[\frac{\partial T}{\partial z}\right]^2\right)^{1/2} \qquad (2)$$

as proposed by Alhussein et al.,(2014)
where |A(x,y) | is the analytic signal's amplitude at (x, y).T denotes the magnetic field that has been observed at (x, y). Nabighian, (1972); Alhussein et al., 2014) explain the analytic signal anomaly over a two-dimensional magnetic contact site at (x = 0) and depth h as illustrated in equations 3 and 4.

$$|A(X)| = \frac{\alpha\ 1}{(h^2+x^2)^{1/2}} \qquad (3)$$

as proposed by Alhussein et al., (2014)
where: α is the amplitude factor

$$\alpha = 2M \sin d\ (1 - \cos^2 (I) \sin^2 (A)) \qquad (4)$$

and h is the depth to the top of the contact, M is the strength of magnetization, d is the dip of the contact, I is the inclination of the magnetization vector and A is the direction of the magnetization vector

3. 4. Upward Continuation

To smooth out near-surface effects, upward continuation was employed. The upward continuation is illustrated in equation 5 (where z is positive downward).

$$F(x, y, -h) = \frac{h}{2\pi} \iint \frac{F(x,y,0)\partial x \partial y}{\sqrt{\left(x-x^i\right)^2+\left(y-y^i\right)^2+h^2}} \quad (5)$$

as proposed by Telford et al., (1990).
where F(x′,y′,-h) = Total field at the point P(x′,y′,-h) above the surface on which F(x,y,0) is known, h = elevation above surface

3. 5. Magnetic susceptibility (M).

The volume magnetic susceptibility, represented by the symbol K as shown in equation 6

$$M = KH \quad (6)$$

where, M is the magnetization of the material (the magnetic dipole moment per unit volume), measured in amperes per meter, and H is the applied field, also measured in amperes per meter. Both quantities are measured in SI units.

The magnetic induction Bis related to Has shown in equation 7

$$B = \mu_0(H + M) = \mu_0(1 + K)H = \mu H \quad (7)$$

where μ_0 is the permeability of free space ($4\pi 10^{-7}$ Henry/m), and μ is the relative permeability of the material. If K is positive, then (1+K) greater than 1 and the material is called paramagnetic.

4. RESULTS AND DISCUSSION

The total magnetic intensity maps of the research area, shown in Fig. 3a and Fig. 3b, demonstrate the magnetic characteristics of distinct lithological units over the Hawal Basement complex. They depict color-coded total magnetic intensity anomaly values, with pink being the highest and blue representing the lowest. These various vares from 8,100 to 7,30 nT.

The variation in the value obtained from this study is similar to a study conducted in Cameroon by Jean et al., (2018) which showed that the total magnetic intensity anomaly highs are dominant in the central (middle) part of the study area, these towns are; Biu, Gombi, Shaffa, Shani, Garkida and Askira.

The high TMI anomalies are due to the basement rock uplift caused by highly magnetic basic igneous intrusions or

from buried magnetic materials such as buried steel casings. Whereas in the northern and southeastern parts of the study area, the total magnetic intensity anomaly lows are dominant. These towns are; Song, Dungma, and Malabu. These are areas with probably intrusive igneous rocks.

While northeastern part around Chibok is depicting a sedimentary basin. This is in agreement with Bassey, (2013) that the Hawal Basement complex dominantly comprises basement rocks.

4. 1. Magnetic Discontinuities and Closures

There are few discontinuities observed on the map (Fig. 4), the most visible discontinuity is at the northern part of study area marked from XXl which may be a boundary that separates the high basaltic rocks at the central part of the study area from the intrusive rocks at the northern part. The northern part may be the area where the sedimentary Chad Basin begins. Salako and Udensi (2013) gave the boundaries between upper Benue Trough and Bornu Basin to be around latitudes 11° 0'N. This corresponds to Chikok area which has the lowest magnetic intensity. The second discontinuity runs diagonally at the southeastern part of the study area marked by YYl. This is indicating the boundary between the dominant high magnetic basement rocks at the central part of the study area and the shallow sedimentary of the Upper Benue Trough as also seen from the Geological map of Nigeria (2006). As previously indicated, Fig. 5, the 3-D map of the study area, clarifies these discontinuities. As shown in (Fig. 4), several magnetic closures of both lows and highs can be discovered in the research area, which is in agreement with the predictions of Bassey et al., (2012). The closure of magnetic lows is indicated by a letter (L), while the closure of magnetic highs is indicated by a letter (H) (Fig. 4). The majority of the high closures are in the study area's central region. There are few magnetic low closures in the northern and southeast parts of the maps.

4. 2. Regional and Residual Separation

The regional map shows a regional trend of east to west, which is unique to work done in the area like; Bassey (2013), Maxwell et al., (2012), and Onuba et al. (2012) that have the regional trend of NE-SW, however, this may be due tothe separation method employed and the eruption of basaltic rocks from the mantle. This same regional trend is noticeable in the upward continuation maps, while the residual trend is a mixture of both east to west and northeast to southwest. The 3-D model of TMI of the Hawal Basement map (Fig. 5) and the regional map of the Hawal Basement (Fig. 6) was generated to enhance simplified data presentation.

4. 3. Upward Continuation

Upward continuation to 2 km has no significant effect on the TMI; some surface features of short wavelength which appear in the original TMI are still present in this map (Fig. 8). But as the data was continued from 10 km to 40 km there are clear differences, surface features of short wavelength keep disappearing living only deep-seated structures of high magnetic intrusive rocks at the central part of the study area, especially around Shellem, Numan, Gombi Shani, and environs(see 10 km (Fig. 9), 20 km (Fig. 10), 30 km (Fig. 11), 35 km (Fig. 12) and 40 km (Fig. 13). The emplacement of these basic igneous materials into the crust then follow with some not reaching the surface but, were trapped within the basement rocks, while extrusive igneous rocks that could be seen at the surface are of shallow depth and could be volcanic center with young basaltic rocks in areas like Biu, Meringa and Gombi as also seen on the modified lineament map of Nigeria (Fig. 2 and Fig. 20). The northern parts of the study area around Chibok are probably the boundaries between the sedimentary Chad basin and the Basement Complex. It is also interesting to note that upward continuation at 40 km is similar to the regional map (Fig. 6) gotten after residual values have been taken out of the total intensity value, both trending east to west (Fig. 7). Mantle upwelling or rising of a mantle plume, which results in crustal stretching and thinning, was also accounted for in sections of the study area by Abubakar et al., (2010) in areas like Shallem, Gombi, Numan, Shani, and surroundings.

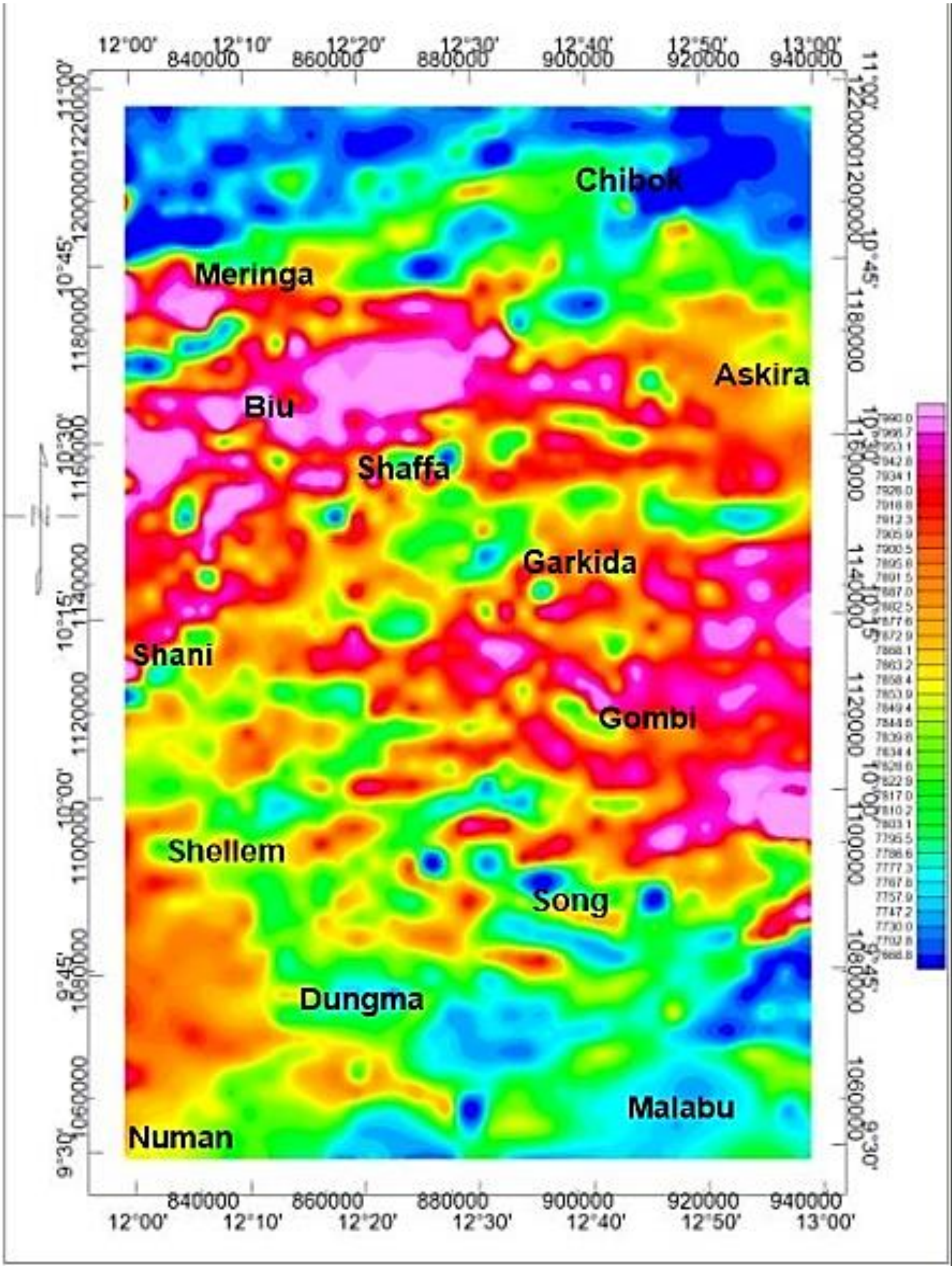

Fig. 3a. Total magnetic intensity map of Hawal Basement (using Oasis Montaj) (after the base value of 25,000 nT has been removed from all data points).

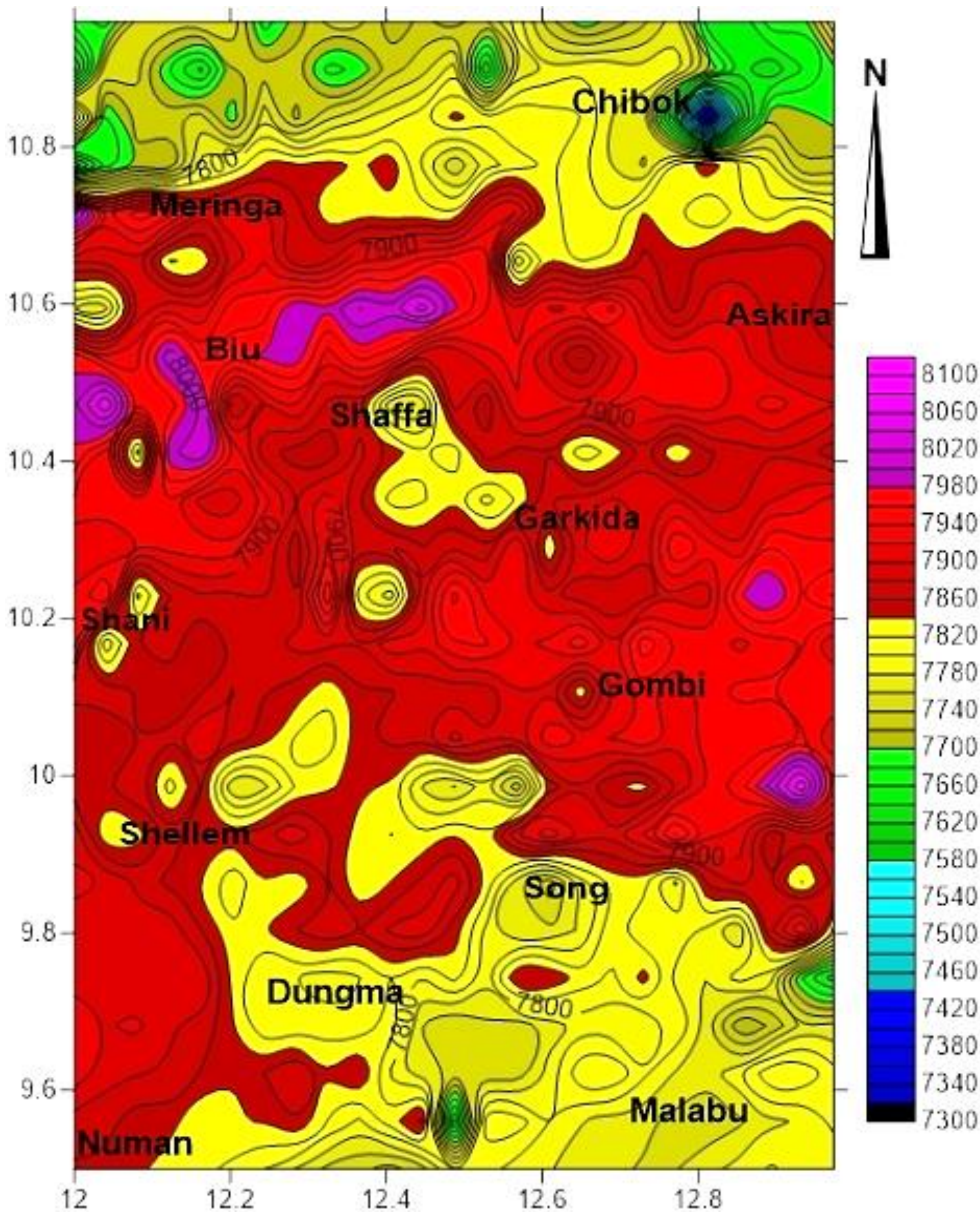

Fig. 3b. Total magnetic intensity map of Hawal Basement (using surfer 10) (Longitude values on X - axis and Latitude values on Y - axis**,** After the base value of 25,000 nT has been removed from all data points).

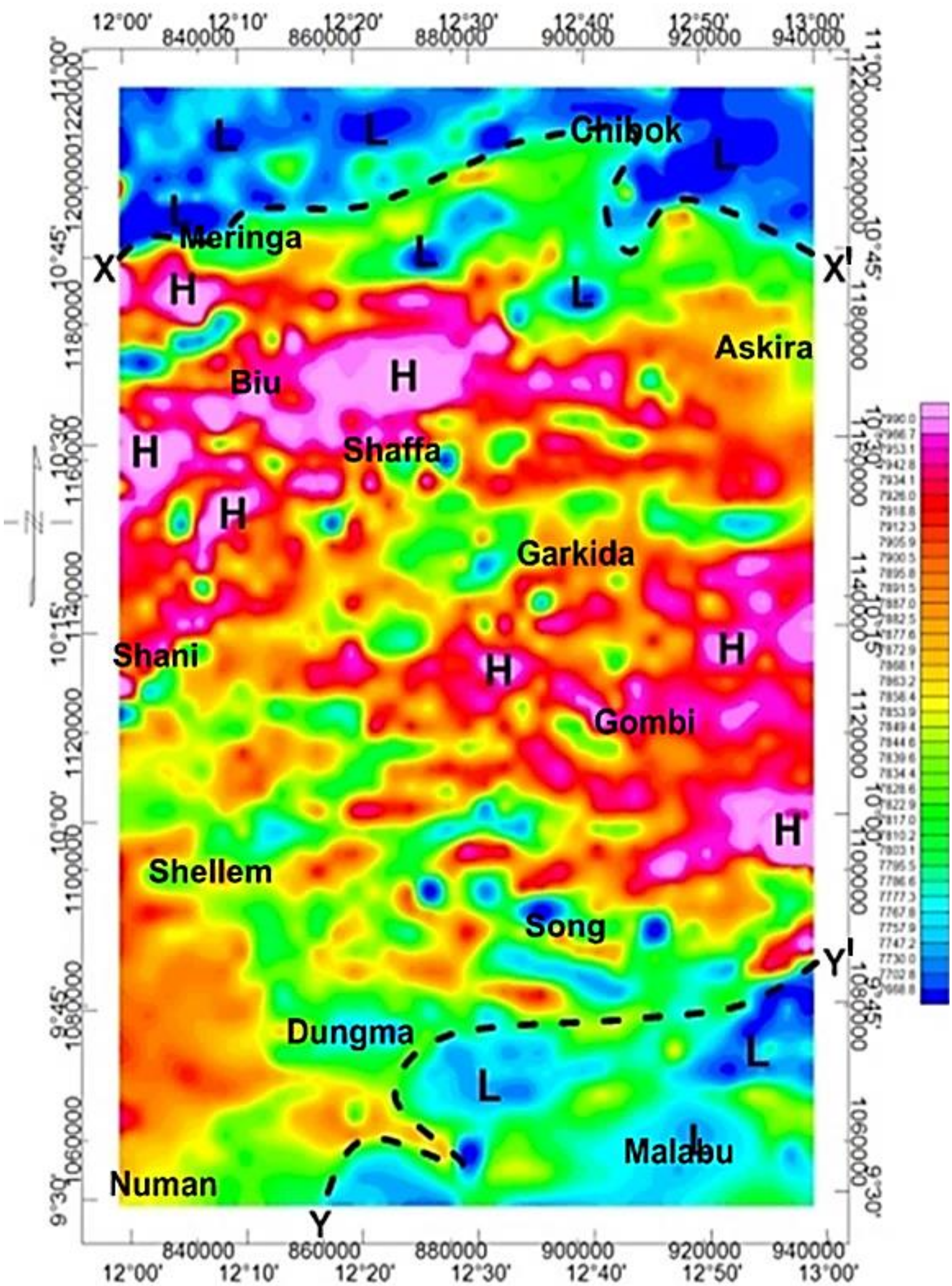

Fig. 4. Total Magnetic Intensity Map of Hawal Basement showing areas of Magnetic Highs (H) and Lows (L) Closures, also with two major Discontinuities xx' and yy'.

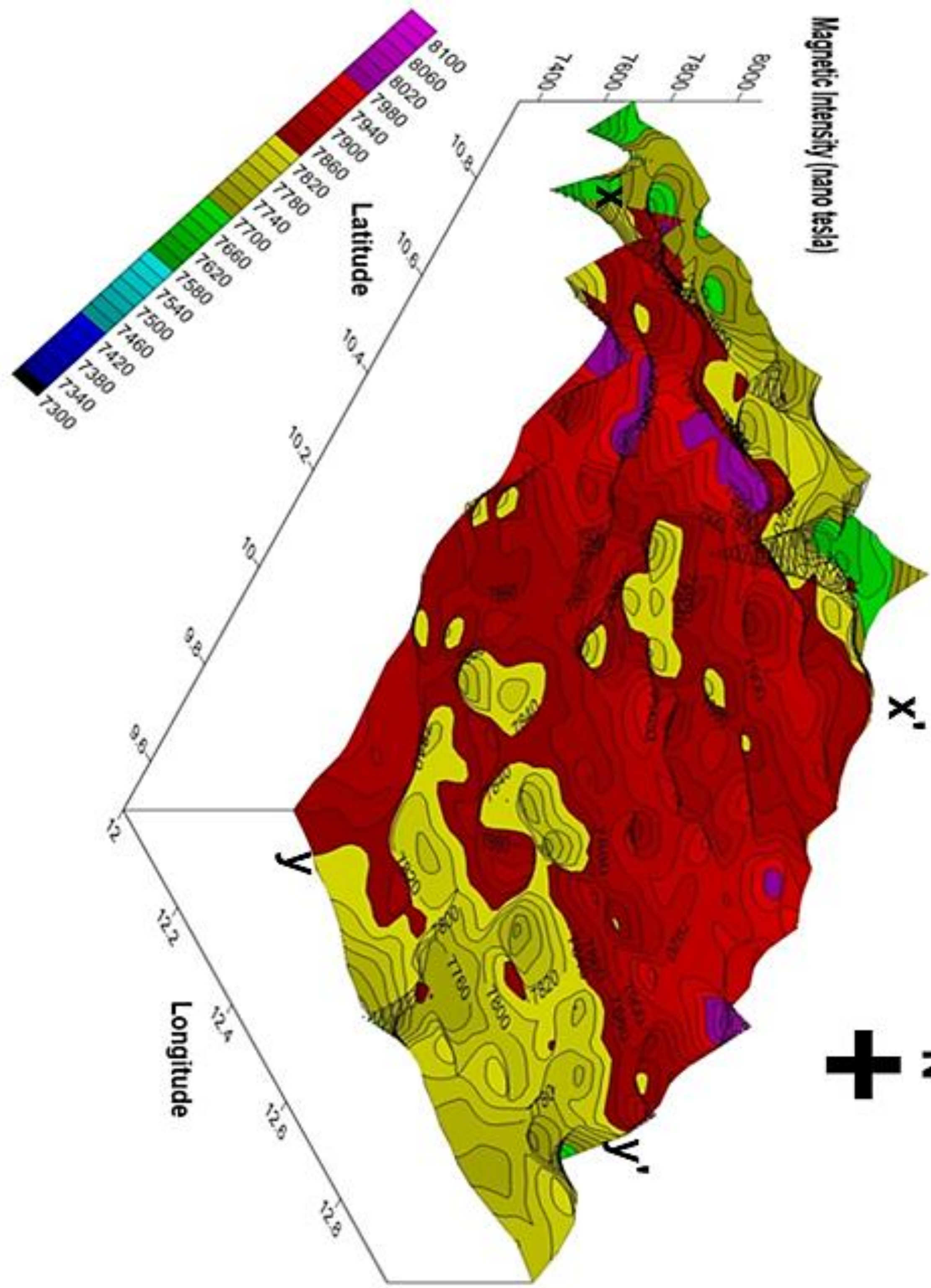

Fig. 5. 3-D model of TMI of Hawal Basement. (Base value of 25,000 nT has been removed from all data points)

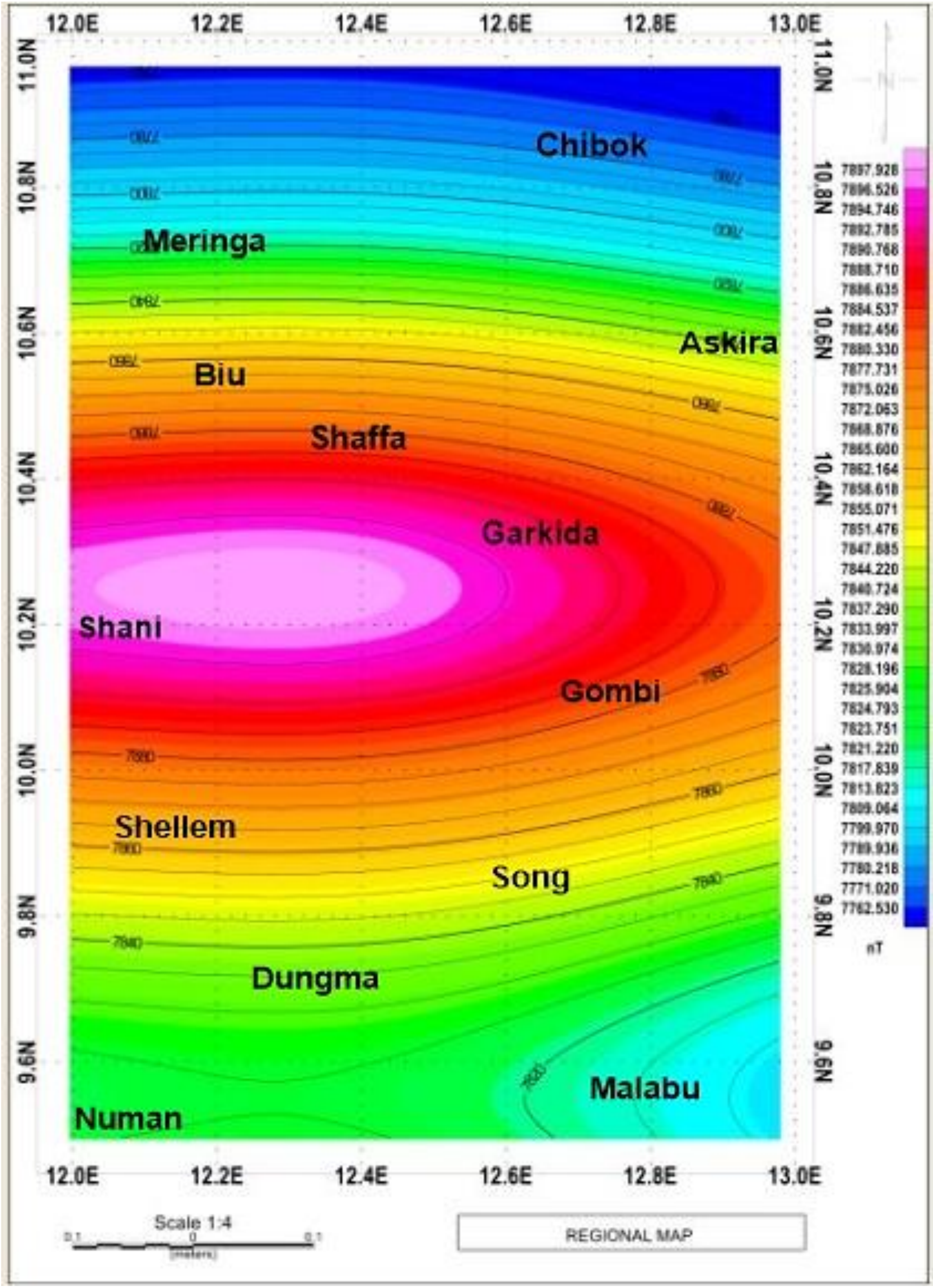

Fig. 6. Regional map of Hawal Basement.

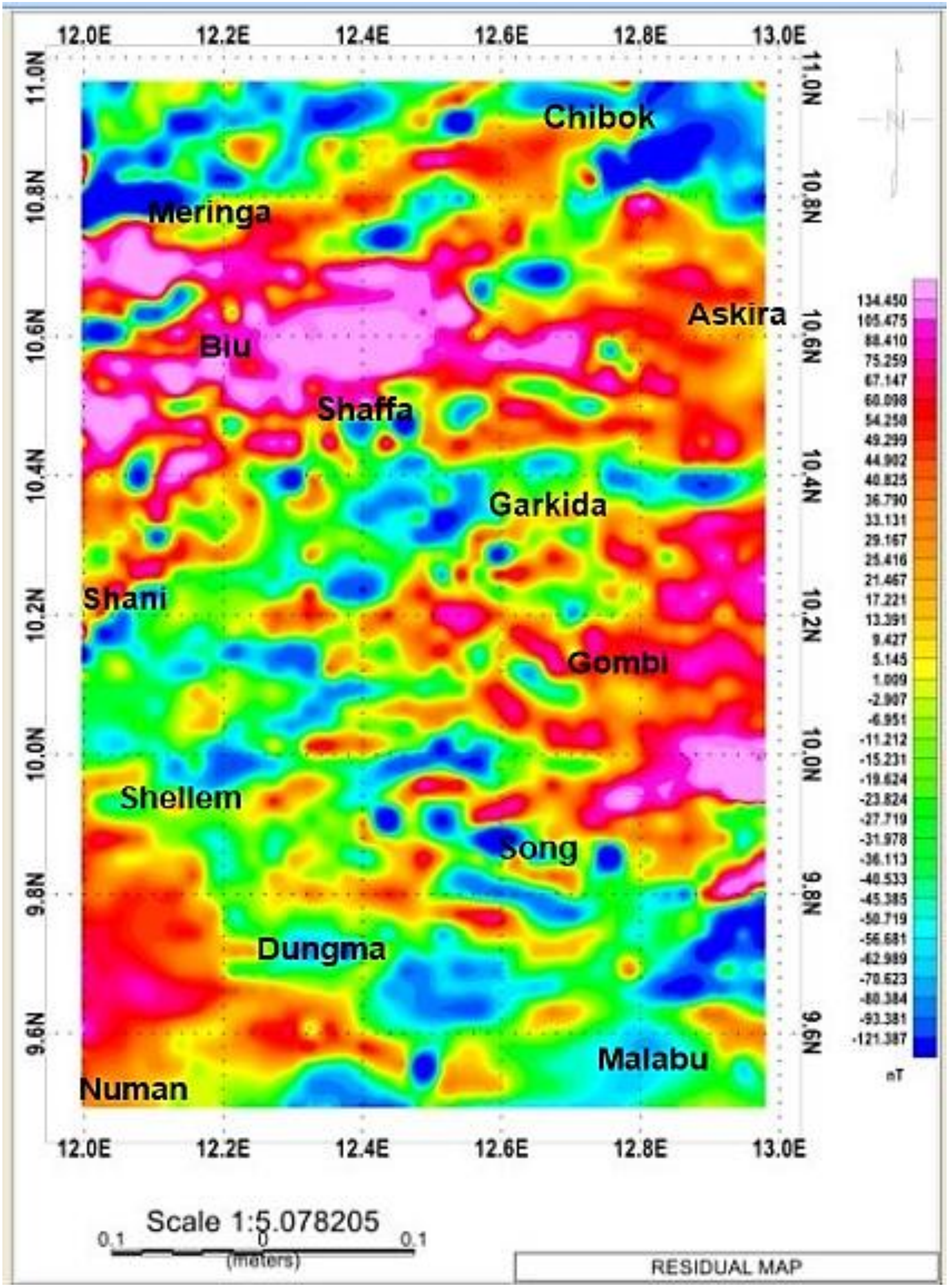

Fig. 7. Residual map of Hawal Basement.

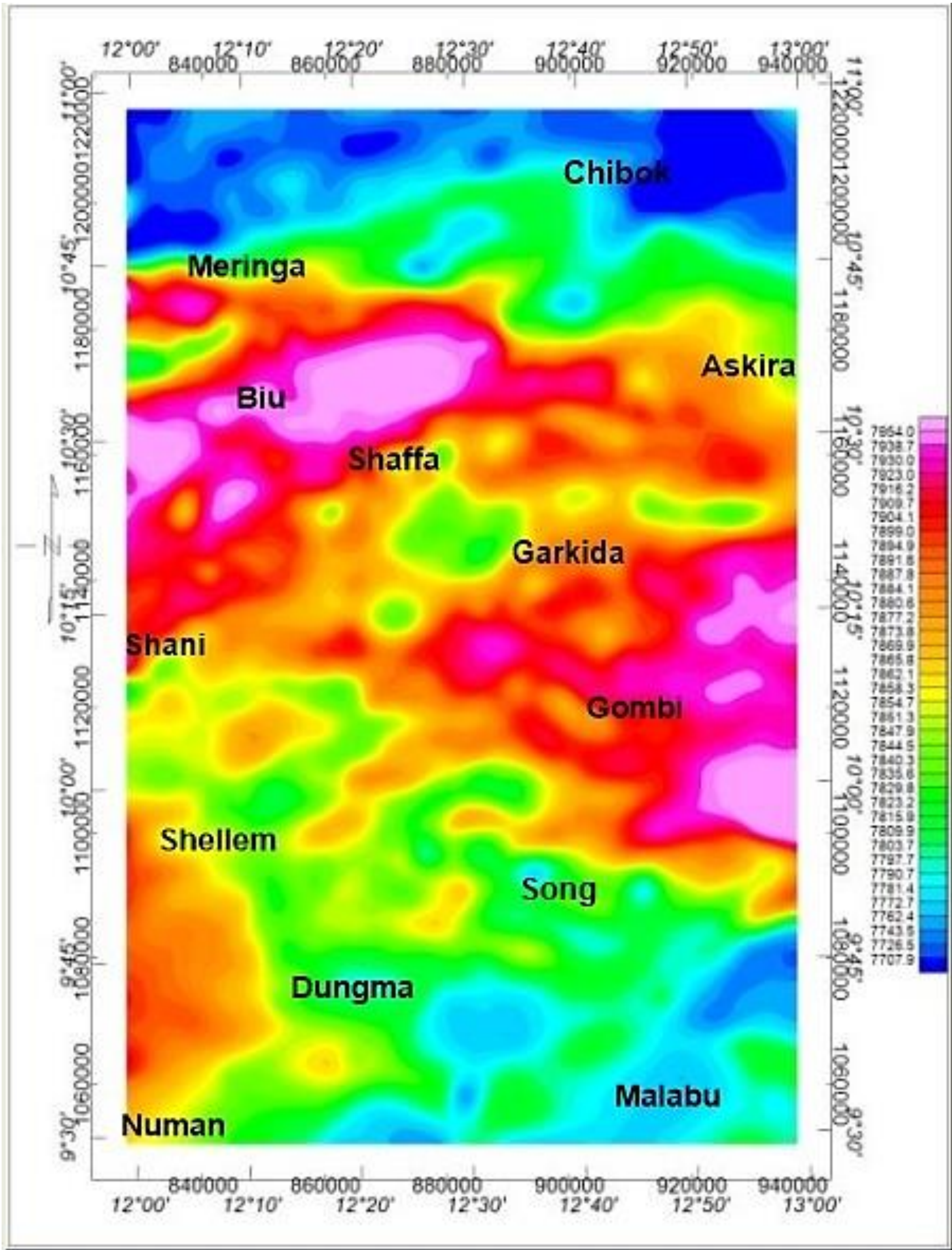

Fig. 8. Upward Continued at 2 km of TMI Map of Hawal Basement.

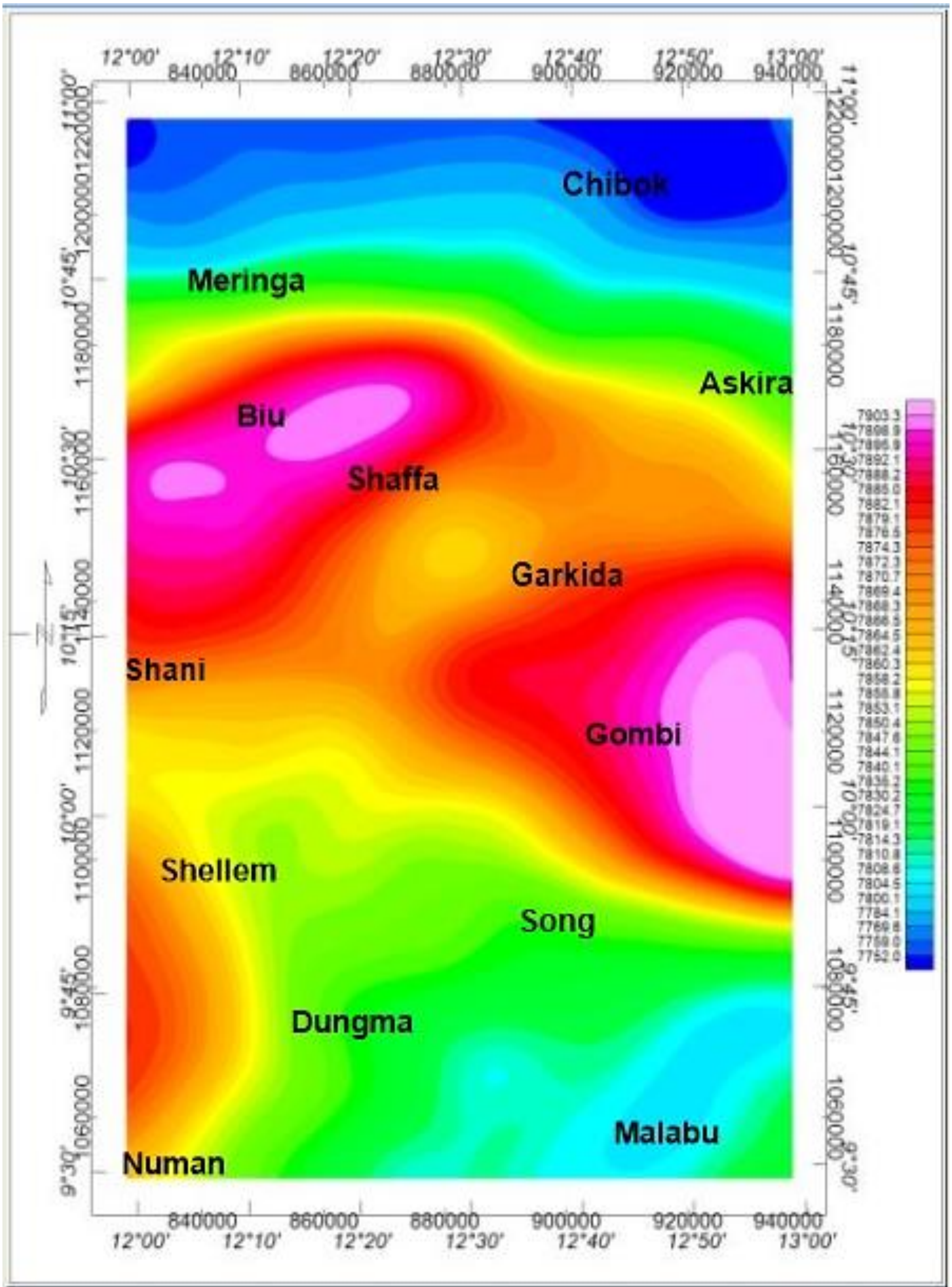

Fig. 9. Upward Continued at 10 km of TMI Map of Hawal Basement.

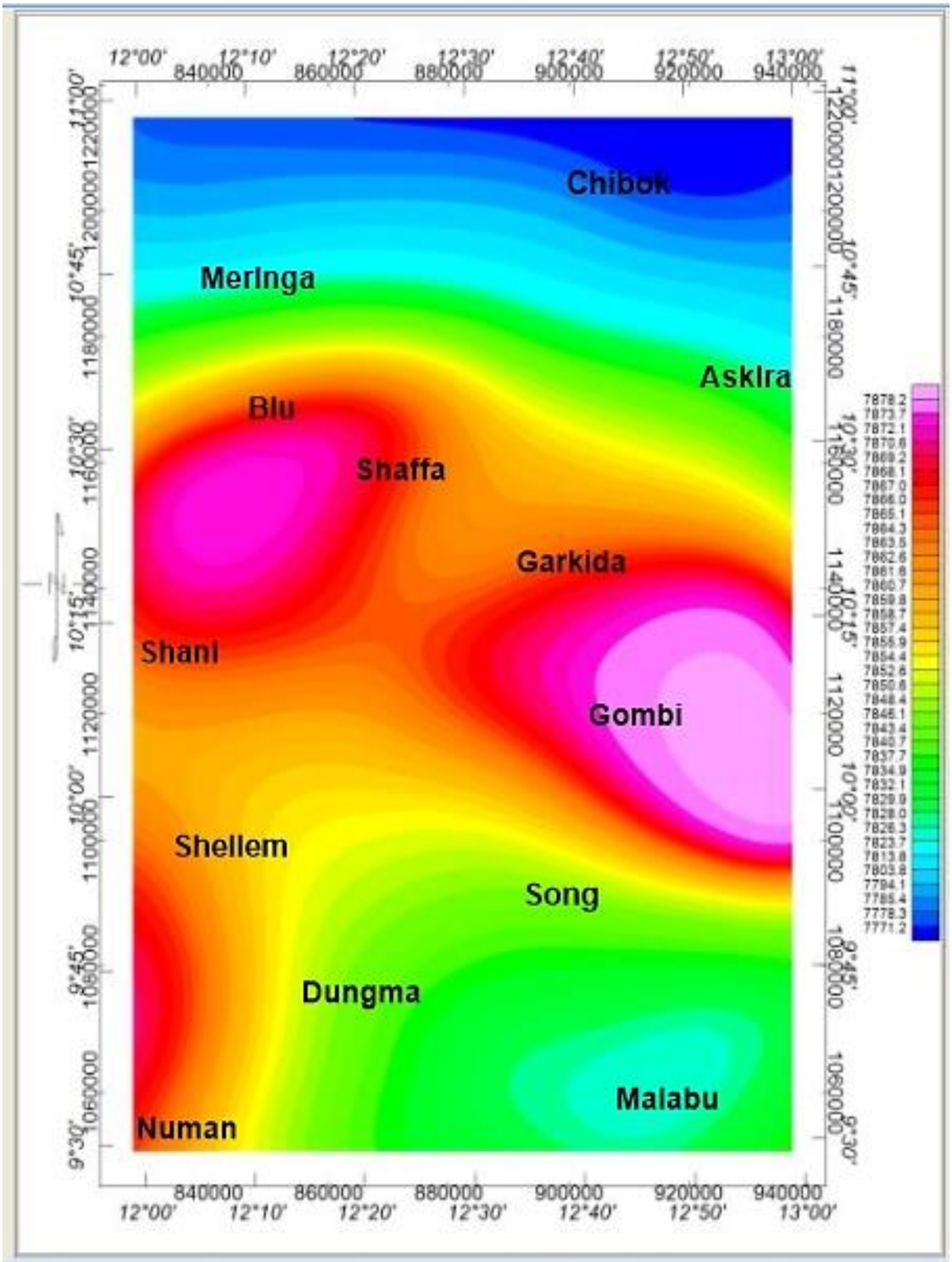

Fig. 10. Upward Continued at 20 km of TMI Map of Hawal Basement.

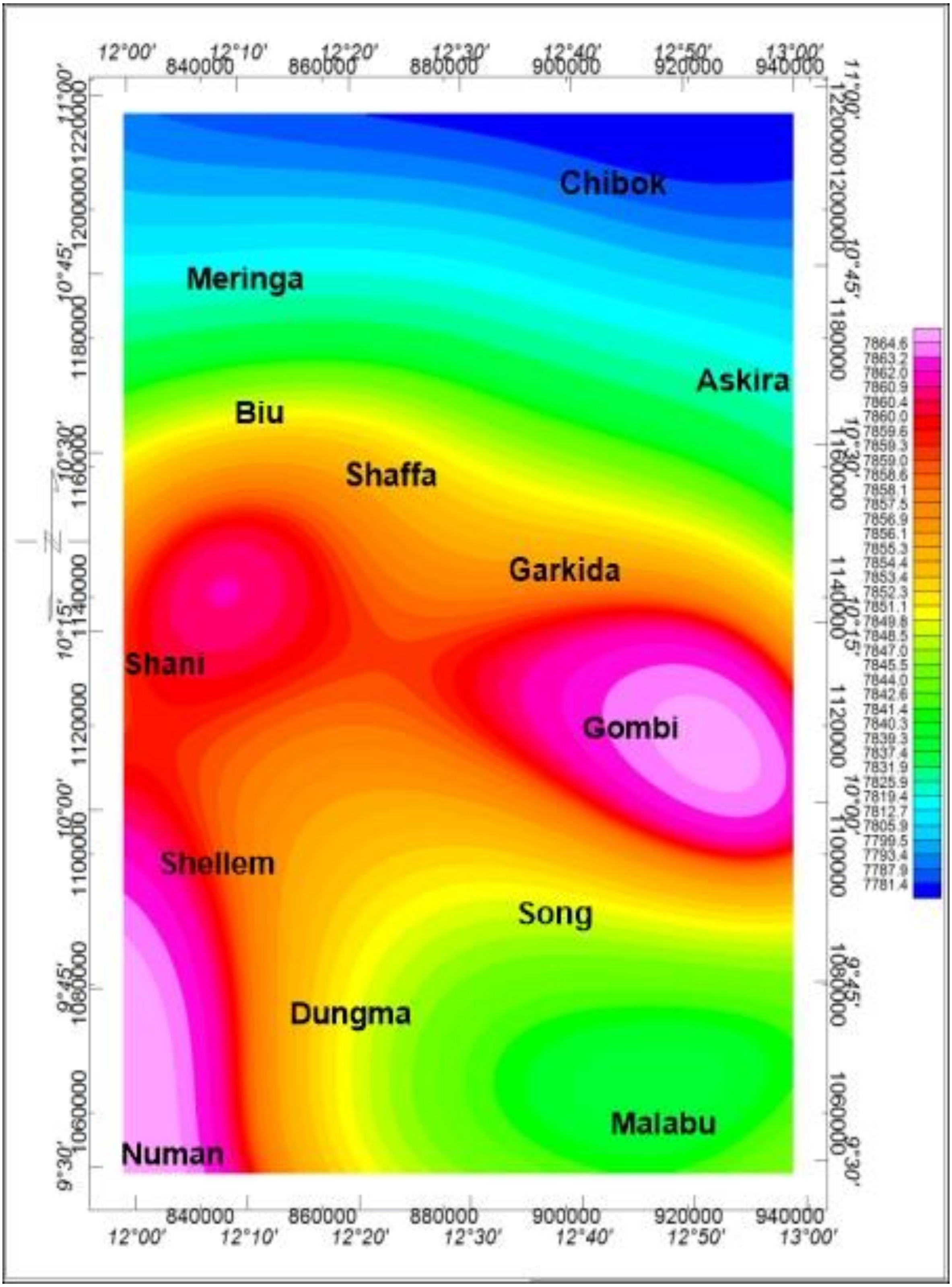

Fig. 11. Upward Continuation of TMI Data of Hawal Basement at 30 km.

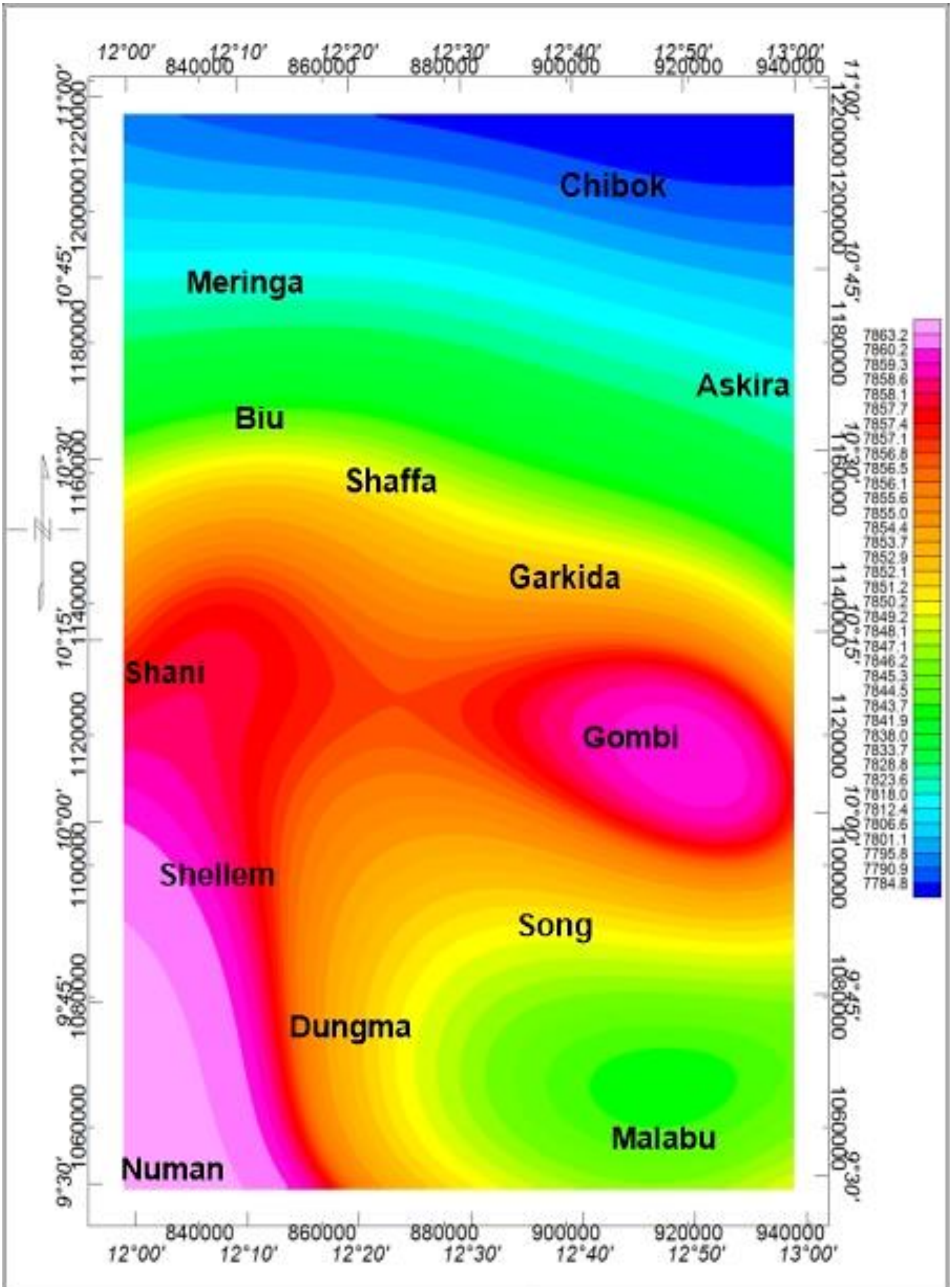

Fig. 12. Upward Continued at 35 km of TMI Map of Hawal Basement.

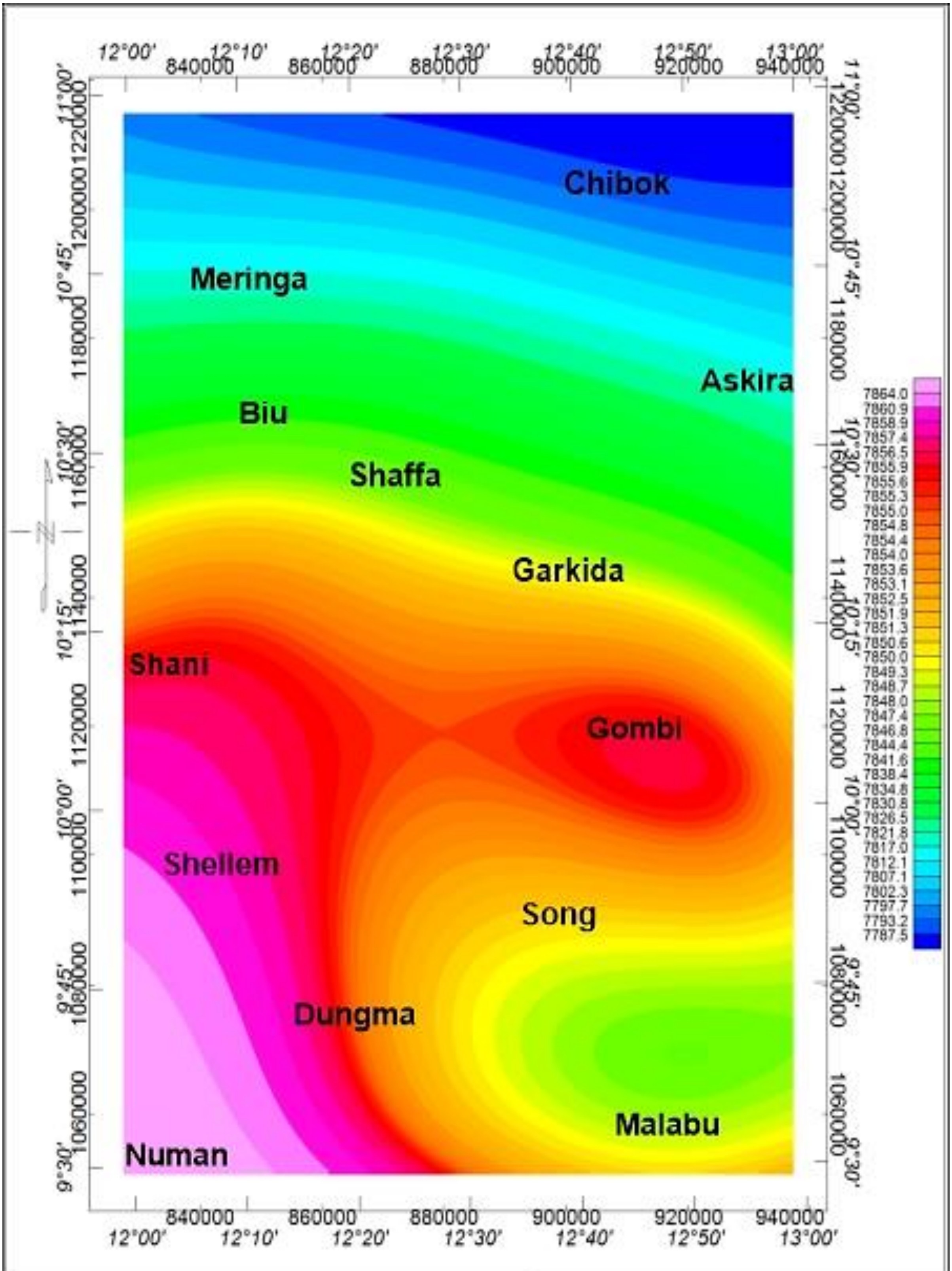

Fig. 13. Upward Continued at 40 km of TMI Map of Hawal Basement.

4. 4. Application of Derivatives on TMI and Result

The application of the derivatives on the TMI produces maps in (Fig. 14 and 15). From the maps produced, most of the anomalies in the dx maps is having a predominant trend of Northeast to Southwest (Fig. 14). While the horizontal derivative map (Fig. 15) shows an anomaly trending east to west which is in line with a study conducted by Bassey and Unachukwu, (2019).

4. 5. Analytical Signal Technique: Results and Analysis

This filter was applied to the TMI data, resulting in the analytic signal map (Fig. 16). Its purpose is to simplify the fact that magnetic bodies typically have a positive and negative peak associated with them, making it difficult to determine the exact location of the causative body, delineate the edges of lithological units, and determine the centers of two-dimensional structural features (Nabighian, 1984,Alhussein et al., 2014).

This filter highlights the causative bodies' edges, which have amplitudes ranging from 7942.499 to 5689.434 Hz (pink colour on the map (Fig. 16). Outcrops of basaltic rocks such as Meringa, Biu, Shaffa, Shani, Song, and its environs derive from the superimposition of multiple lava flows and lay unconformably on the Pan-African Basement (Guiruad, 1989).

The basalts of lower Gongola (Shani region) are transitional alkaline basaltic flows with a Mesozoic age of 146 Ma, according to Benkhelil (1989) and (Guiruad, 1989), whereas the Song basalt is of Tertiary in age. Areas with red coloration (amplitudes ranging from 5385.039 to 4210.944), such as Shellem, Dungma, and others, are most likely areas with fresh basement intrusion. Areas with yellow to green (of amplitude ranging from 3974.494 to 136.944) are weathered Basement rocks.

Areas with light blue (of amplitude ranging from -132.119 to -2689.580) colour depicted old weathered basement rocks. These are in agreement with (Bassey, 2013) who acknowledge the presence of extrusive rocks like younger basalt and basalt in some parts of the Hawa Basement Complex.

The analytical filter revealed that the emplacement of these basic rocks (younger basalt and basalt) were tectonically controlled and that their emplacement took advantage of pre-existing fissures or lineament in the study area (Junaid et al, 2019, Olaniran and Ogbonnaya, 2018).

In addition, the alignment of closures tends to mark out likely trends of magnetic lineaments, trending NE to SW, NW to SE, few E to W, and N to S.

4. 6. Euler Deconvolution.

The result of the standard Euler map in Fig. 17 shows that most of the structures in the study area have an average thickness of 249 meters.

The colour doi.org/10.1016/j.ecoenv.2014.09.008 legend at the bottom of the map shows the range of thickness on the basement rock to be from -249.980 meters to -249.969 meters, with the blue having the maximum thickness of -249.989 m to the pink having the lowest thickness of -249.969 m.

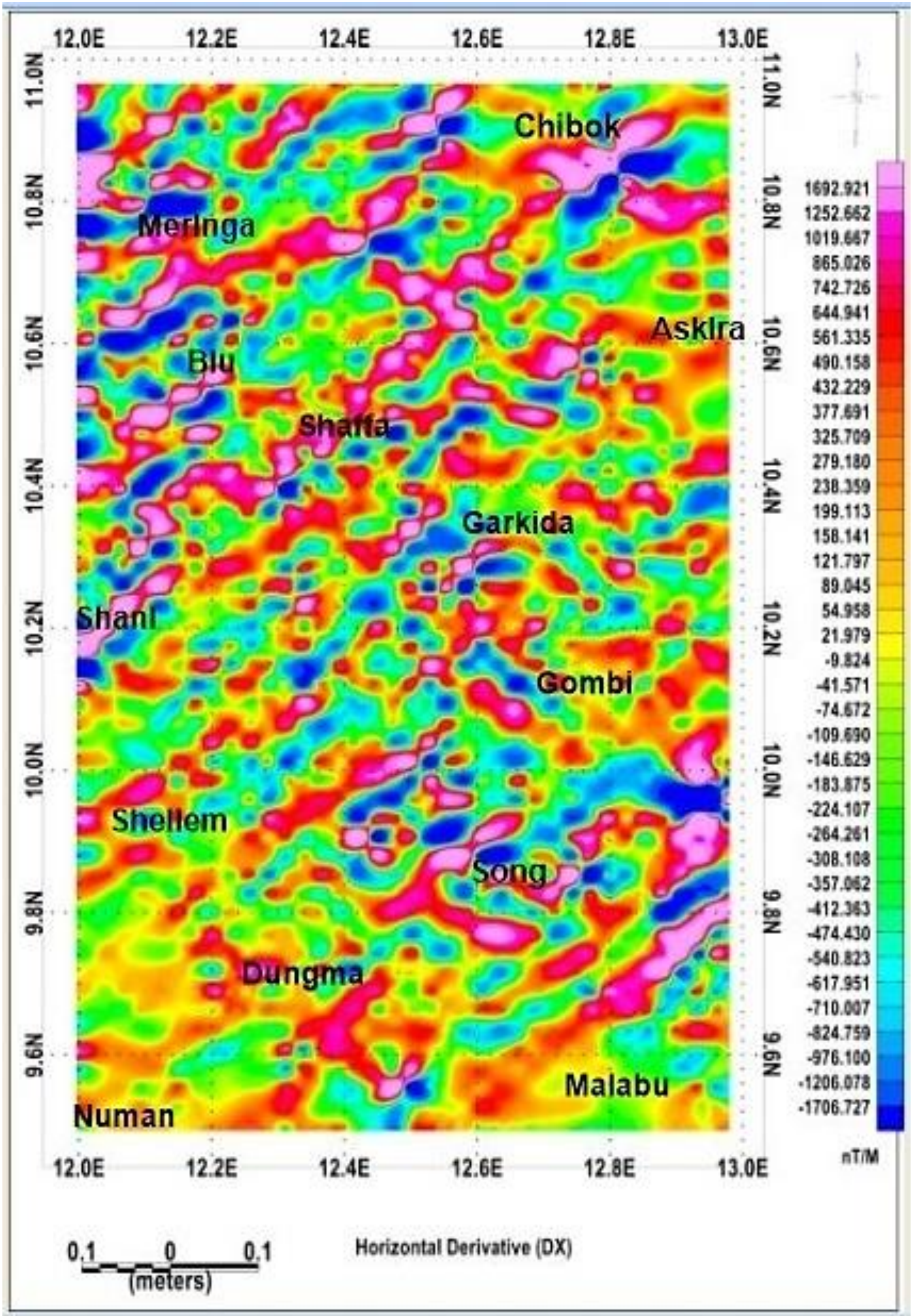

Fig. 14. Horizontal Derivative (Dx) Map of Hawal Basement.

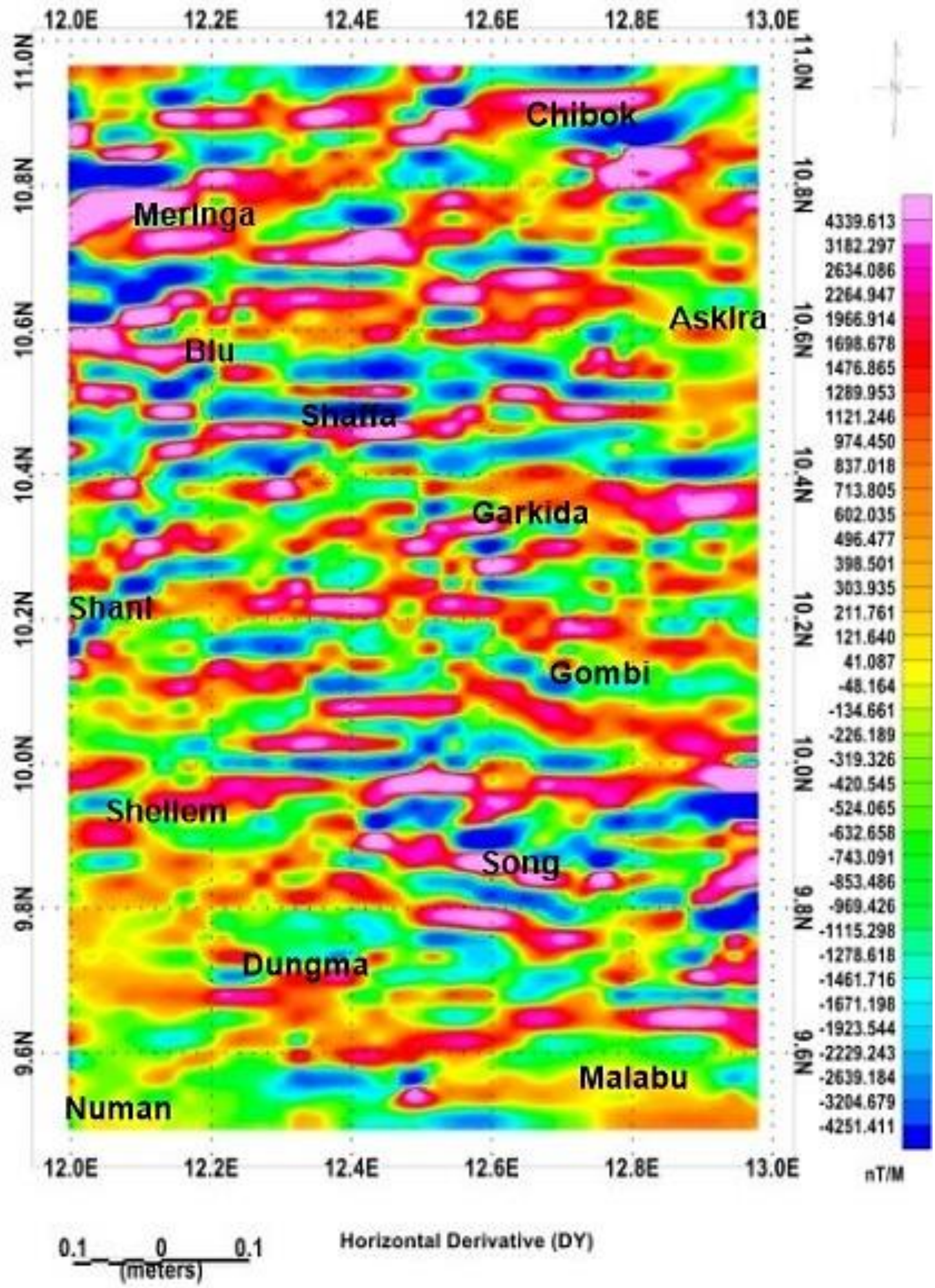

Fig. 15. Horizontal Derivative (Dy) Map of Hawal Basement.

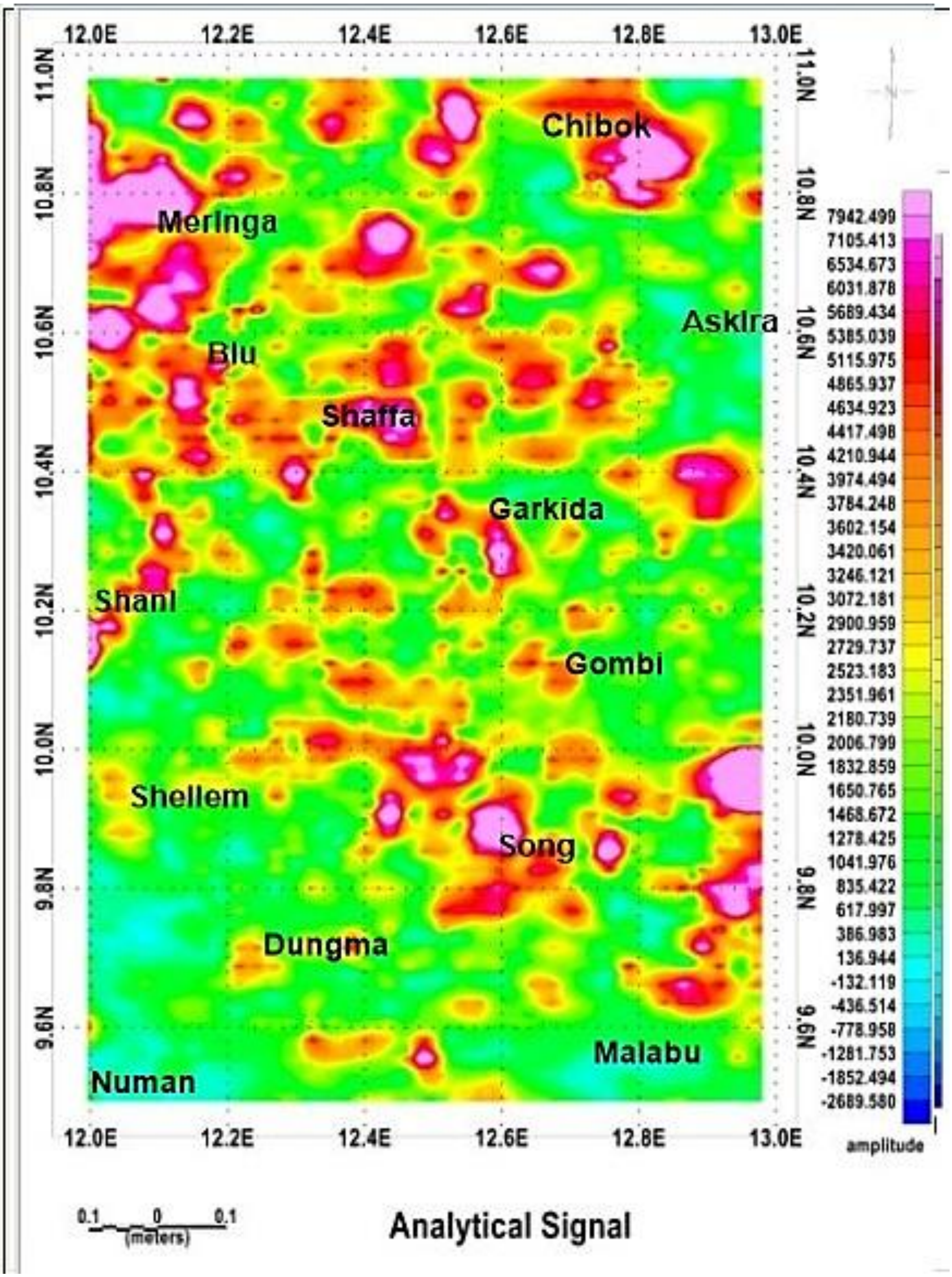

Fig. 16. Analytical Signal Map of Hawal Basement.

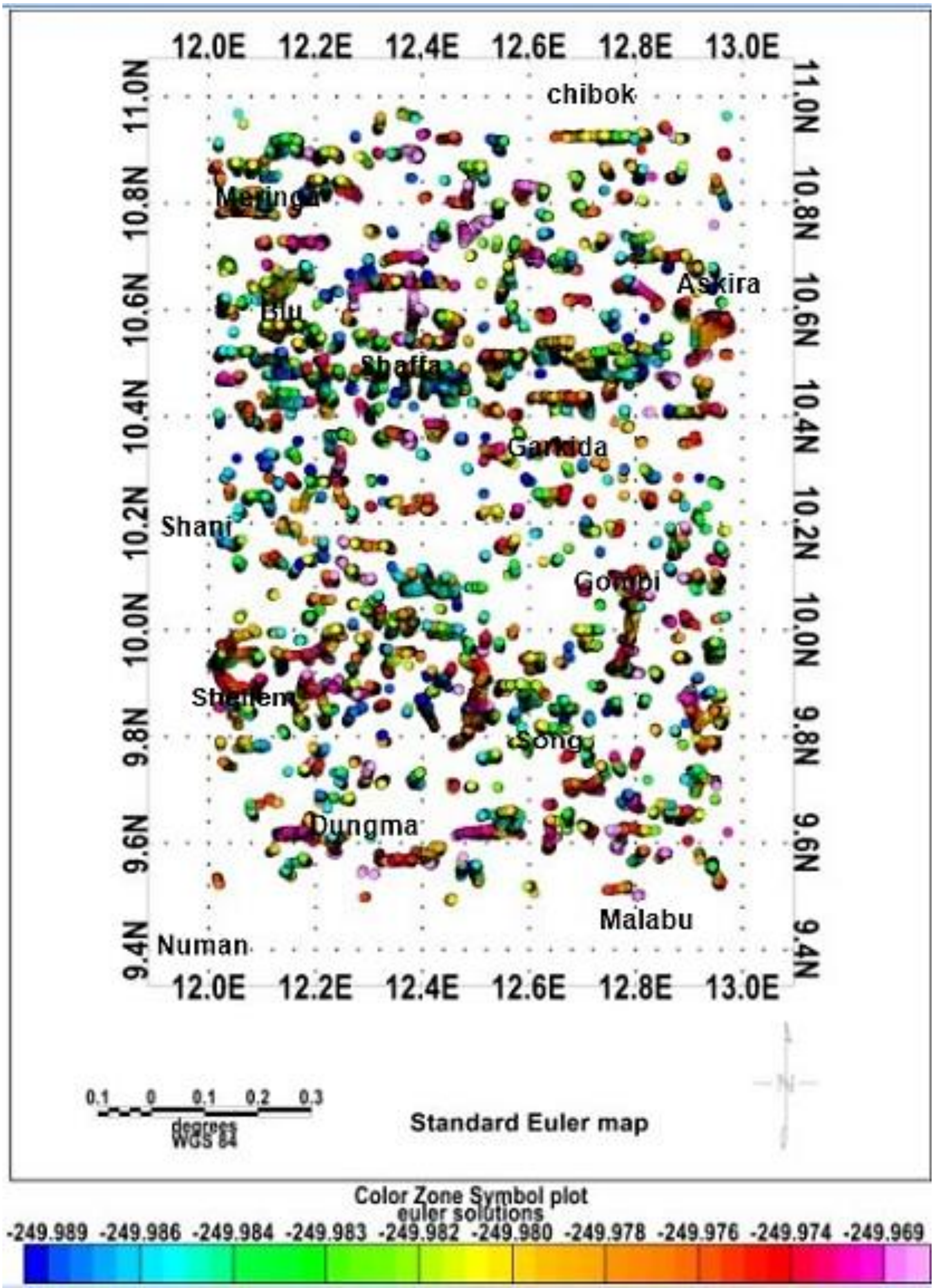

Fig. 17. Standard Euler Map of Hawal Basement.

4. 7. Lineaments and Deformation in the Study Area

To improve the mapping of anomalies along fault lines, the total magnetic intensity map of the study area was subjected to both first and second vertical derivatives. The first and second vertical derivative maps are shown in Fig. 18 and 19 respectively. From the first vertical derivative map (Fig. 18), the structures (lineaments) are mapped out using black strikes, which gives a clear alignment of anomalies, while the second derivative map demarcates the boundaries of these anomalies. From the multiple fault lines seen on the maps, one can assume the area of study is a fracture zone. The major lineament trend is NE to SW, with minor NW to SE and E to W trends. Magnetic activity in the Upper Benue Trough occurred in two significant events, according to Benkhelil (1989) and Abubakar et al., (2010). The first episode occurred in the Mesozoic, and it included the Jurassic Burashika Complex and the Cretaceous basaltic veins, which were constrained to faults trending N 55 0 (Carter, Barber, Tait, and Jones 1963).

The second phase occurred during the tertiary, coinciding with the Cameroon volcanic line's intense alkaline magmatic activity. The tertiary phase of magmatic activity is manifested as Biu basalt. The second phase occurred during the tertiary, coinciding with the Cameroon volcanic line's high alkaline magmatic activity. The third phase of magmatic activity is manifested as Biu basal (Benkhelil, 1989; Abubakar et al., 2010).

The existence of these two major episodes of magmatism in parts of the study area (Biu plateau) with a tertiary episode which outcrop in the form of basalts strongly suggest that the basic rocks observed at depth in the area of study are the product of volcanism at depth in the area due to openings such as faults, joints, and fractures, this is similar to study conducted by Abubakar et al., (2010).

This emplacement of basic igneous materials in the crust then follow with some not reaching the surface but was trapped within the Basement rocks as seen in areas like Shani, Shellem, Numan, and Gombi when viewed from Upward continued to 30 km. Benkhelil (1982, 1986) studied the alignment of volcanic rocks in the upper Benue Trough and came to the same conclusion. Benkhelil (1982, 1986) studies included portions of the Hawal Basement complex, and according to Guiraud (1989), the area has undergone deformation from 146 Ma and 127 Ma during the Mesozoic to Tertiary period.

4. 8. Structural Trends

The first vertical derivative map (Fig. 18) depicts the various structure lineaments. The predominant structural trends are NE-SW, NW-SE, and a few E-W. As a result, the magnetic lineaments observed in the area, like most of the known structures in and around the Benue Trough and Chad Basin, are trending in the major direction of NE–SW. It is most likely a magmatic failed rift within the Gongola arm of the trough, buried at a depth of around 8 km (Shemang et al., 2001).

The lineaments in Figs 21 and 22 are very similar to the Nigerian Lineament map and modified lineament map developed by the Geological Survey of Nigeria in 2006. Both suggest that the studied area has several fault lines, most of which trend in NE-SW directions with a few in NW-SE and E-W directions, which is consistent with findings conducted by Bassey et al., (2012). Furthermore, the study area digital elevation map (Fig. 22) showed that the study area is characterized by low to medium elevation topography with drainage directions moving towards NE-SW, N-S, and NW-SE, which correspond to main river courses and foliation trends.

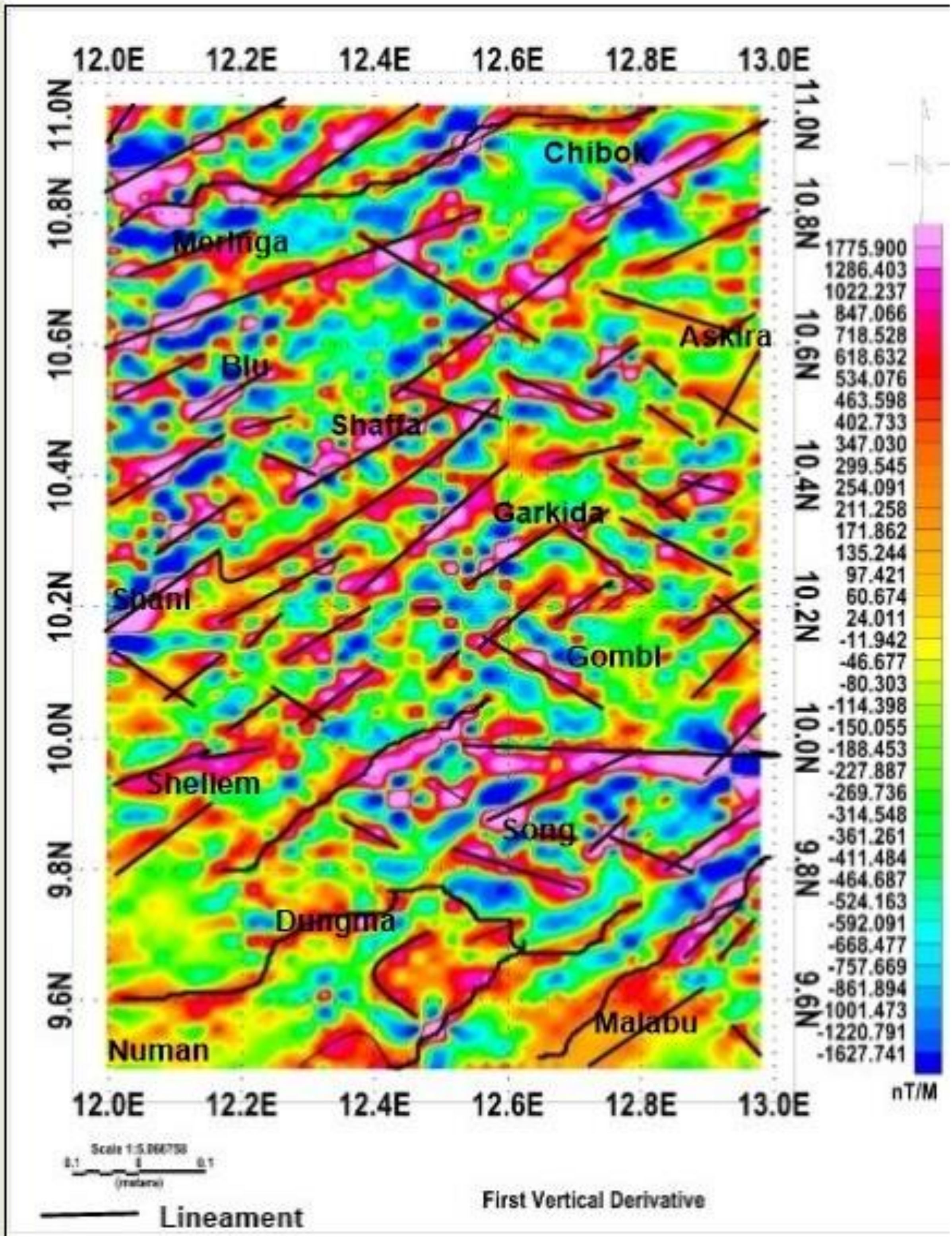

Fig. 18. First vertical Derivative Map with lineament of Hawal Basement.

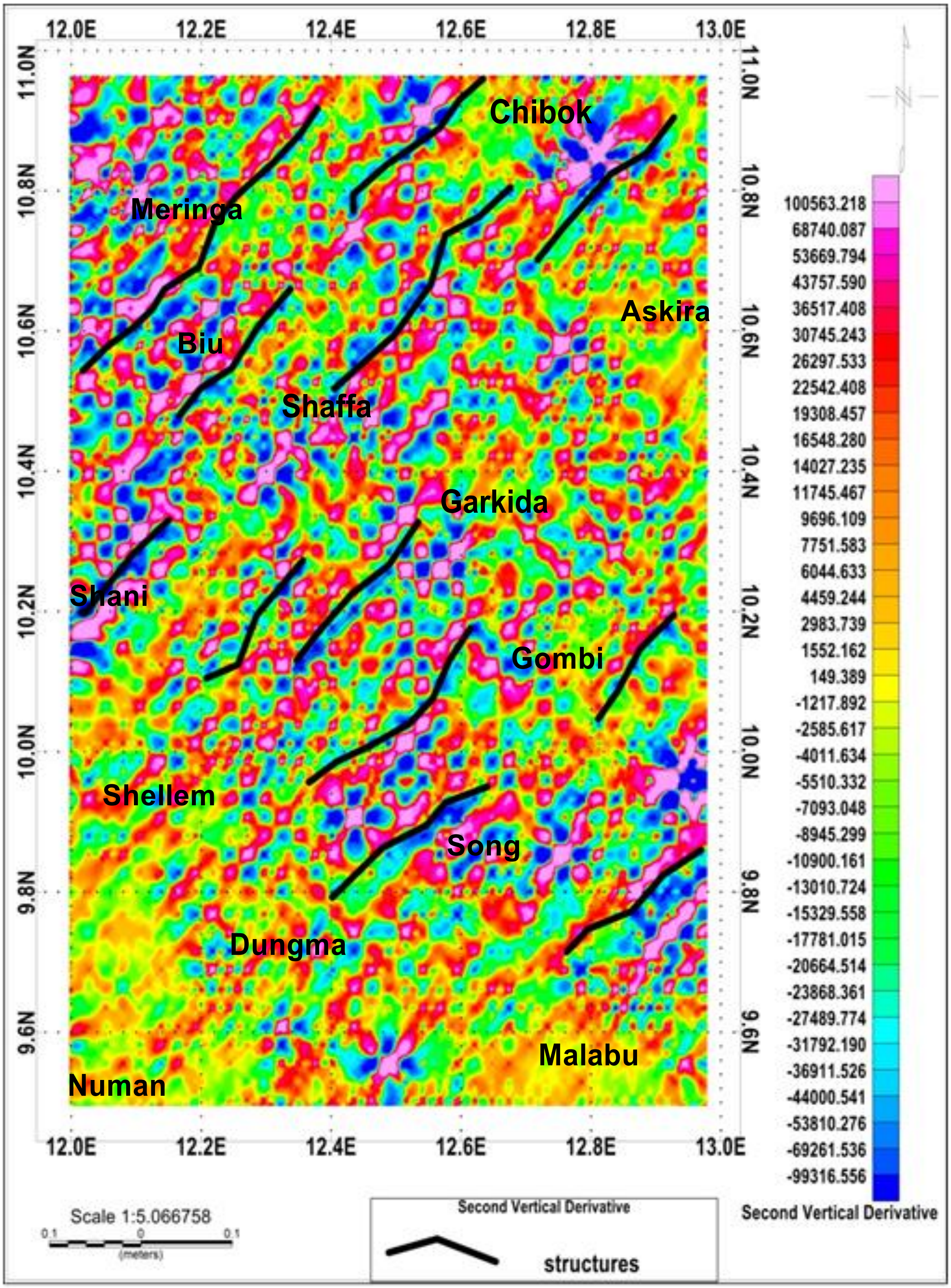

Fig. 19. Second Derivative map with Structures of Hawal Basement.

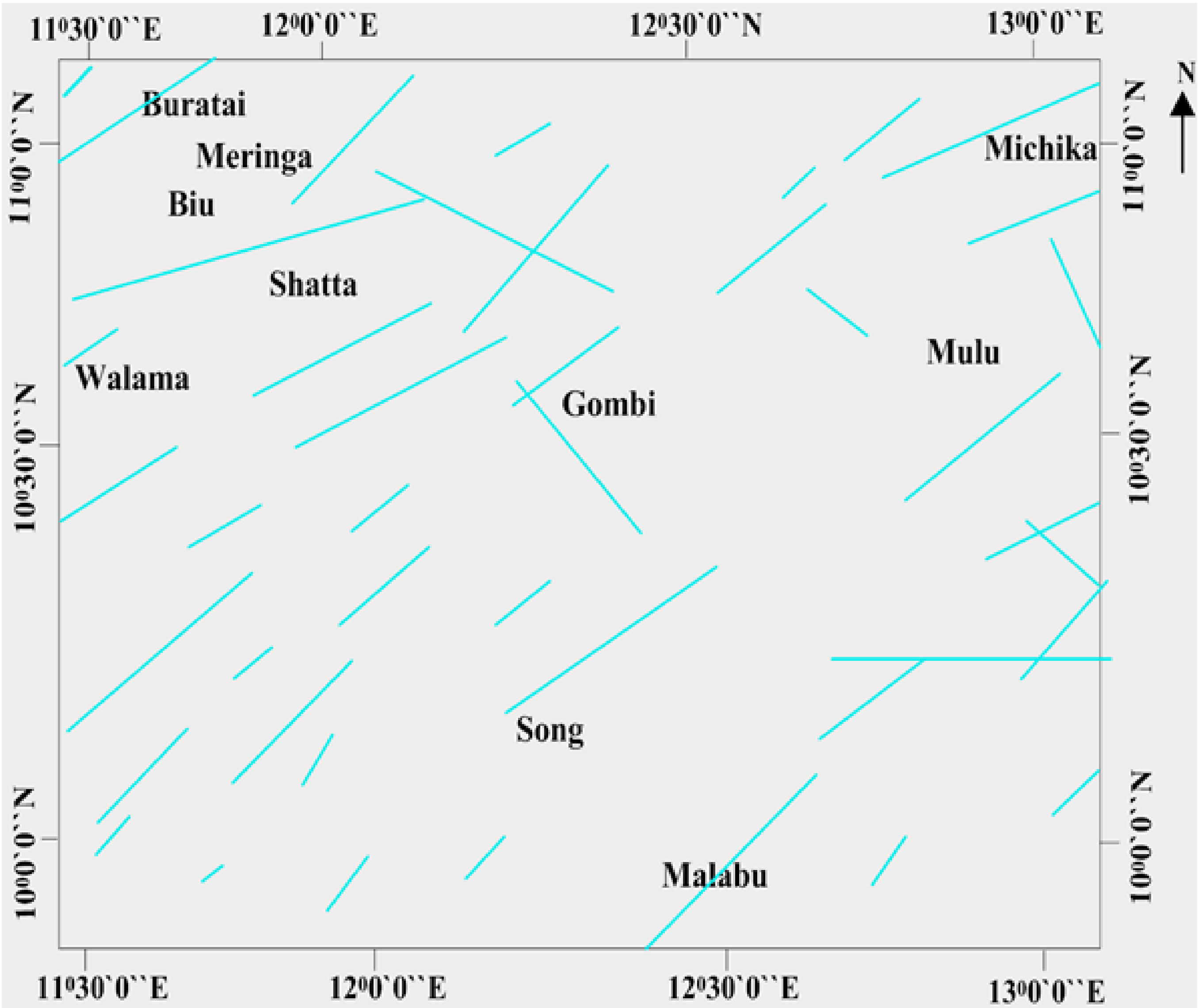

Fig. 20. Lineament map of the study area.

4. 9. Mineralisation

From the total intensity map (Fig. 3a), second derivative map (Fig. 19), and analytical map(Fig. 16) these towns; Meringa, Biu, Shani, Song, Garkida, Shaffa, and their environs have some basic necessity for mineralization, because of the presence of high magnetic intensity, fault lines, and fresh extrusive rocks. These, therefore, suggest that these towns are promising to have the mineral potential for exploration. This is in line with a 2004 publication by the Adamawa State Government, which stated that the state has a variety of minerals, including iron ore, cassiterite, uranium, trona, manganese, and magnesite.Garnet, aquamarine, spinel, amethyst, and topaz are among the precious stones featured (Ministry of Commerce, Industries and Solid Minerals Development, Adamawa State 2004).

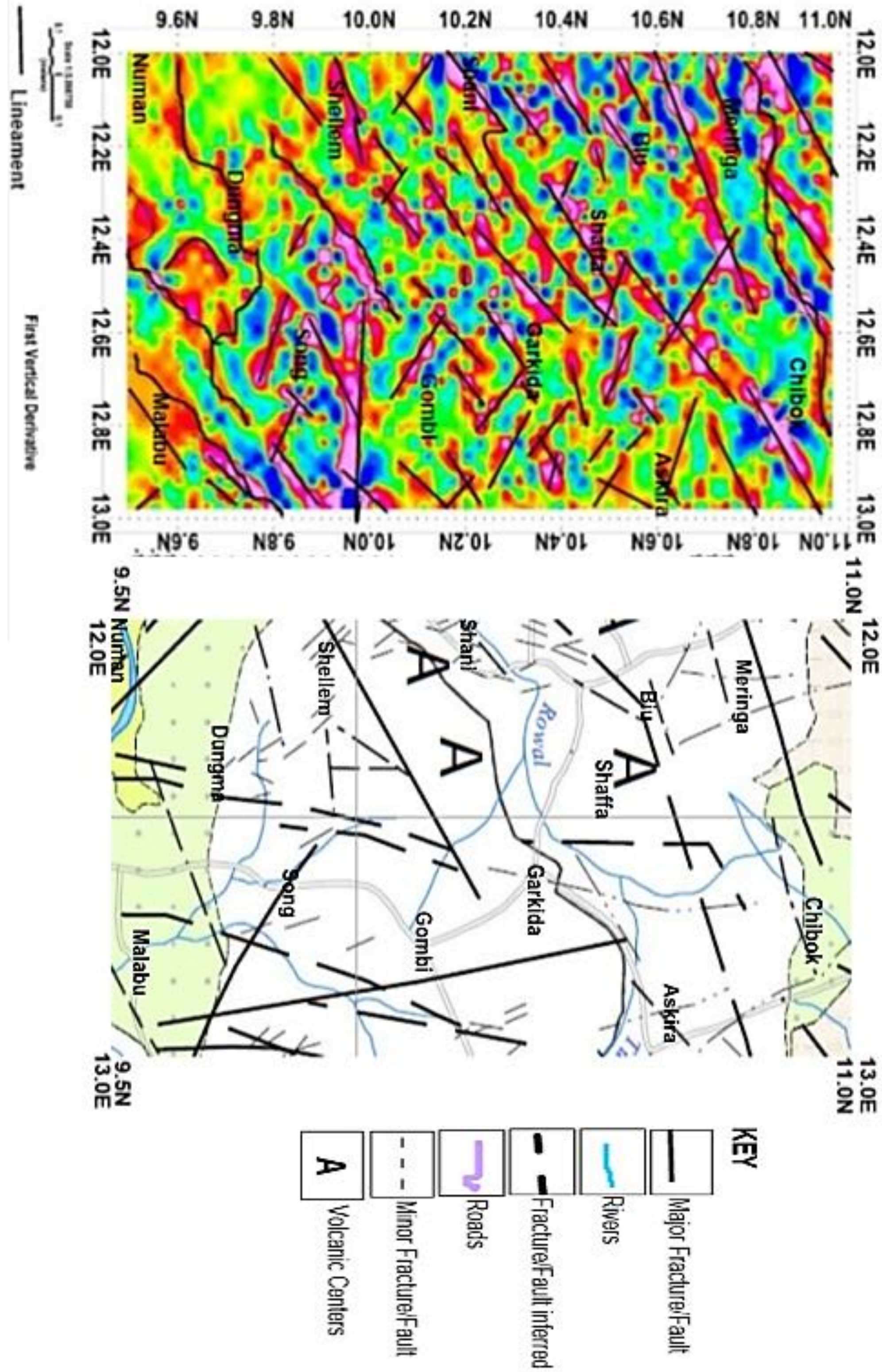

Fig. 21. Lineament map of Hawal Basement compared with the Modifieid lineament map of Nigeria (GSN 2006).

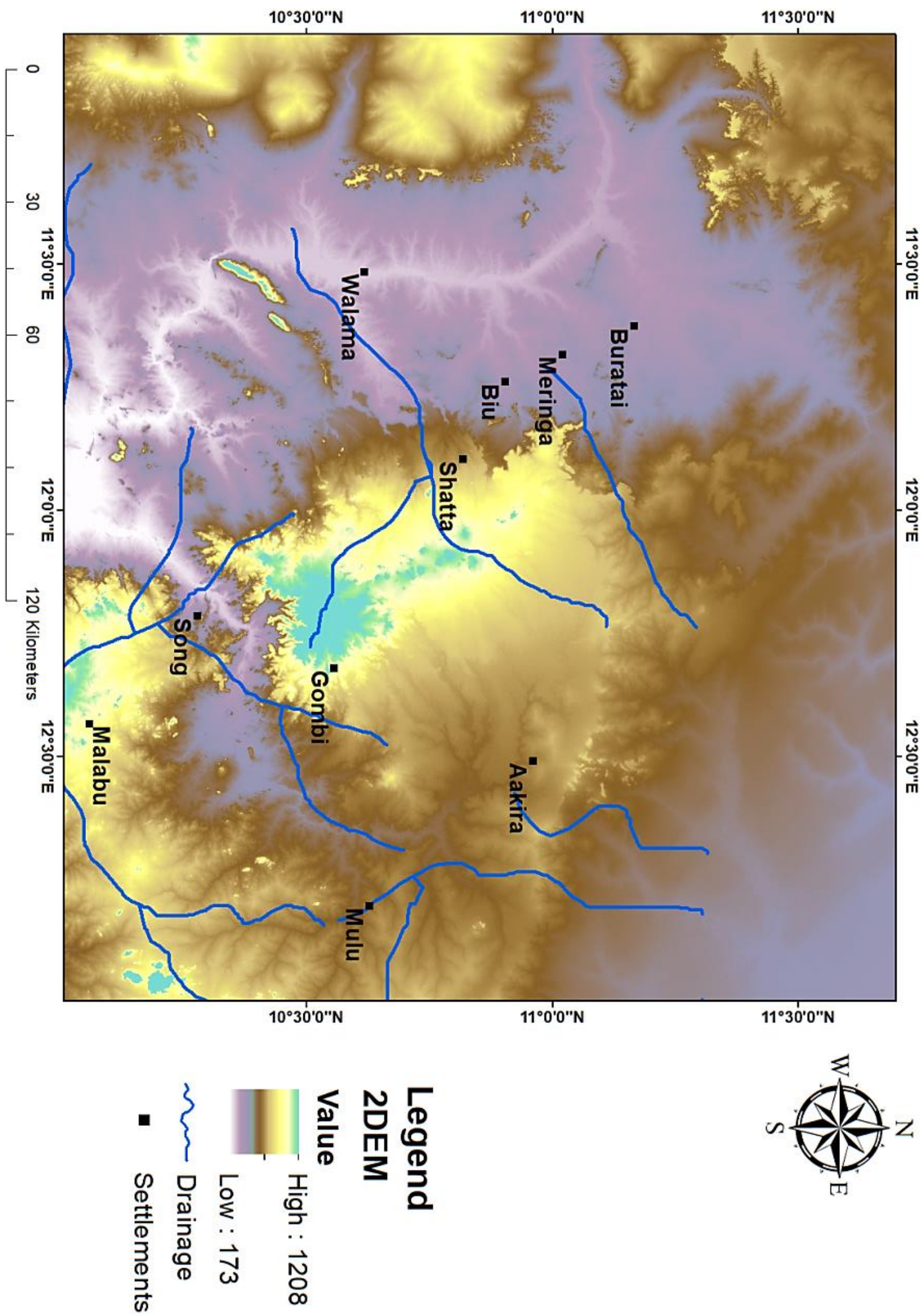

Fig. 22. Digital elevation map of the study area.

5. CONCLUSIONS

The research area is characterized by a fracture zone with an acute magnetic lineament structure trending in the directions of NW-SE, NE-SW, and slight E-W on the map of the first vertical derivative. According to the findings of this study, the magnetic lineament found in the area is largely moving in the same direction (NE–SW) as most of the known structures in and around the Benue Trough and Chad Basin. In Precambrian shields and basement rocks from all continents, the NE-SW, NW-SE, and N-S lineament trends have been detected regularly. Although the exact cause of their development is uncertain, global tectonics is largely thought to be involved. According to findings, the main lineaments trending are NW-SE, E-W, and NE-SW, which are consistent with earlier research.

The total magnetic intensity result indicates that the basement complex has numerous magnetic abnormalities.

The evidence of tectonic control on the emplacement of basic rocks, which is strong along the NE-SW direction, is depicted by the consistent alignment of lineament. Pre-existing cracks or lineament were used to position this regular alignment in the Precambrian. The Hawal, Song, and Yedseram rivers are all close to the Basement Complex. The mineral deposition could occur if mineralizing fluids invade the alignment zones.

References

[1] Abubakar M. B. (2014). Petroleum Potentials of the Nigerian Benue Trough and Anambra Basin: A Regional Synthesis. *Natural Resources*, Vol. 5 No. 1.

[2] Abubakar, Y.I., M.N. Umegu and S.B. Ojo, (2010). Evolution of Gongola Basin Upper Benue Trough Northeastern Nigeria. *Asian Journal of Earth Sciences* 3(2):62-72, DOI:10.3923/ajes.2010.62.72

[3] Ademakinwa G O, Ponmile J.E, Martins O. O, Michael O.O and Gaius A.O (2020): The magnetic method as a tool in groundwater investigation in a basement complex terrain: Modomo Southwest Nigeria as a case study. *Applied Water Science* (2020) 10: 190 https://doi.org/10.1007/s13201-020-01279-z

[4] Alhussein A.B, Abdelnasser M. A, Ahmed E, Ayman I.T, Mohammed A.A, (2014): Tracing of the Avenue of the Ram-Headed Sphinxes Remains Using Geophysical Investigations, Luxor, Egypt. *International Journal of Geosciences*, Vol. 5 No. 8,

[5] Bassey, N. E., Dike, E. F. C., & Likkason, O. K. (2012). Digital filtering of aeromagnetic maps for lineaments detection in Hawal Basement Complex of Hawal Area, NE Nigeria. *Journal of mining and Geology*, 48 (1), 1-11

[6] Bassey, N. E. (2013). Statistical study of alignment of volcanic and sub- volcanic basic rocks in Hawal Basement Complex northeast Nigeria. *U.S. Open Environment and Earth Science Journal*, 1 (1), 01-13

[7] Bassey N.E. and Unachukwu H.N (2019): Geological analysis of ground radiometric survey data of Hong hills, Hawal basement complex, N. E. Nigeria. *Journal of Geology and Mining Research.* Vol. 11(3), pp. 22-30

[8] Benkhelil, J. (1982). Structural map of Upper Benue Valley. *Journal of Mining and Geology*, 18, 140-151

[9] Benkhelil, J. (1986). Structure and geodynamic evolution of the Intracontinental Benue Trough (Nigeria). Doctoral Thesis, University of Nice, France, Elf Nigeria Ltd Publication

[10] Benkhelil, J. (1989). The origin and evolution of the Cretaceous Benue Trough, Nigeria. *J Afr Earth Sci* 8, 251–282

[11] Bruce, B., & Rhea, L. G. (1996). Dictionary of mining, minerals and Related terms (2nd ed.). U.S. Bureau of Mines.

[12] Carter, J. D., Barber, W., Tait, E. A., & Jones, G. P. (1963). The geology of parts of Adamawa, Bauchi and Bornu provinces in North-Eastern Nigeria. *Bulletin Geological Survey Nigeria*, 30, 1-99

[13] Chinwuko, A. I., Onwuemesi, A. G., Anakwuba, E. K., Okeke, H. C., Onuba L. N.,Okonkwo, C.C., & Ikumbur, E. B. (2013). Spectral Analysis and Magnetic Modeling over Biu – Damboa, Northeastern Nigeria. *Journal of Applied Geology and Geophysics,* 1(1), 2321- 0982

[14] Christopher O.A and Alaga A.T (2016). Geological Lineament Extraction Using Landsat 8 (OLI) in Parts of Osun State, Southwestern Nigeria. *International Journal of Science and Research* Volume 5 Issue 8, 9-12, DOI: 10.21275/ART2016414

[15] Cratchley, C. R., & Jones, G. P. (1965). An interpretation of the geology and gravity anomalies of the Benue valley, Nigeria. *Overseas Geological Surveys Geophysical Paper,* 1, 1-26

[16] Falconer, J. D. (1911). The geology and geography of Northern Nigeria. Macmillan, London, 135pp.

[17] Geinnet, R. H. (1975). Airborne remote sensors applied to engineering geology and civil works design investigations. Technical Report, TR- 17621, Motorola Aerial Remote Sensing Incorporated, Phoenix. Arizona

[18] Geological Survey of Nigeria, (1974). Geological Map of Nigeria. Scale 1:2,000,000. Geological survey of Nigeria, Kaduna, Nigeria.

[19] Geological Survey of Nigeria, (2006). Geological Map of Nigeria. Scale 1:4,402,912. Geological survey of Nigeria, Kaduna, Nigeria.

[20] Guiraud, M. (1989). Geological map of part of Upper Benue valley-explanatory note. ELF Nigeria Ltd.

[21] Jean A. M, Theophile N.M, Marcelin B .B, Jean D.N, Olivier U.O. (2018). Inferring the Subsurface Basement Depth and the Contact Locations from Aeromagnetic Data over Loum-Minta Area (Centre-East Cameroon. *International Journal of Geosciences,* 9, 435-459

[22] Qadir, J., Bhat, M.S., Alam, A. *et al.* Mapping groundwater potential zones using remote sensing and GIS approach in Jammu Himalaya, Jammu and Kashmir. *GeoJournal* 85, 487–504 (2020). https://doi.org/10.1007/s10708-019-09981-5

[23] Kogbe, C. A. (1989). Geology of Nigeria, (2nd ed). Jos, Rockview Nigeria Ltd, pp. 538.

[24] Maxwell, O., Husin, W., Noorddin, I., Ugwuoke P.E. (2012). Aeromagnetic data interpretation of the triple junction area of the Upper Benue Trough, northeastern Nigeria. *Journal of Environmental Research And Development*, 7(2A), 811-819

[25] Megwara J.U and Udesi 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) (2013) 115-124

[26] Ministry of Commerce, Industries & Solid Minerals Development, Adamawa State (2004). Adamawa Solid Minerals. Published by Adamawa State Government, 32p.

[27] Nabighian, M. N. (1984). Toward a three dimensional automatic interpretation of potential field data via generalized Hilbert transform. Fundamental relations. *Geophysics*, 47, 780-786

[28] Nigerian Geological Survey Agency (2006). Lineaments map of Nigeria. Published by the authority of the federal republic of Nigeria, 2006

[29] Obaje, N.G. (2009). Geology and Mineral Resources of Nigeria. In: S. Bhattacharji, H. J. Brooklyn, Neugebauer, J. Bonn, Reitner, Gottingen, & K. Stuwe (Eds.), Lecture Notes in Earth Sciences, Springer: Graz Publisher

[30] Ofoegbu, C. O., (1985). A Review of Geology of the Benue Trough, Nigeria. *Journal of African Earth Sciences*. 3 (3), 281-291

[31] Ohi J. O (2020): Detection of Sulphide Deposit Using Uranium/Potassium Ratio Map. *Ghana Journal of Geography* Vol. 12(1), pages 145-158

[32] Aluko, O.E., Igwe, O. Automated Geological lineaments mapping for groundwater exploration in the basement complex terrain of Akoko-Edo area, Edo-State Nigeria using remote sensing techniques. *Model. Earth Syst. Environ.* 4, 1527–1536 (2018). https://doi.org/10.1007/s40808-018-0511-4

[33] Onuba, L. O., Chinwuko, A. I., Onwuemesi, A. G., Anakwuba, E. K., & Nwokeabia, N. C. (2012). Interpretation of aeromagnetic anomalies over parts of Upper Benue Trough and Southern Chad Basin, Nigeria. *Pelagia Research Library Advances in Applied Science Research*, 3 (3), 1757-1766

[34] Oyawoye, M.O. (1964). The contact relationship of charnockite and biotite gneiss at Bauchi, Northern Nigeria. *Geology Magazine*, 10, 138-144

[35] Roest, R. W., Verhoef, J., & Pilkington, M. (1992). Magnetic interpretation using the three dimensional analytic signal. *Geophysics*, 57, 116–125

[36] Salako, K. A., & Udensi, E. E. (2013). Spectral Depth Analysis of Parts of Upper Benue Trough and Borno Basin, North-East Nigeria, Using Aeromagnetic Data. *International Journal of Science and Research*, 2(8), 48-55

[37] Shemang, E. M., Ajayi, C. O., & Jacoby, W. R. (2001). A magmatic failed rift beneath the Gongola arm of the Upper Benue Trough, Nigeria. *Journal of Geodynamics*, 32, 355-371

[38] Telford, W. M., Geldart, L. P., & Sheriff, R. E. (1990). Applied Geophysics. (2nd ed.). Cambridge University Press.

[39] Zaborski, P.M. (1998). A review of the Cretaceous System in Nigeria. *Africa Geoscience Review* 5, 385-483