

AERO-GEOPHYSICAL ANALYSIS OF STRUCTURES IN NORTHWESTERN NIGERIA

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ABSTRACT

The importance of the exploration of the inland basins in Nigeria cannot be over emphasised. If they are found and used, hydrocarbons will expand the nation's supply and increase output. All of these will benefit the nation strategically and economically. The Iullemeden basin is a sizable synclinal basin, of which the Sokoto Sedimentary Basin is the southeast portion. The total magnetic intensity and residual maps were created using the data obtained from the digitization of twenty-nine aeromagnetic maps of the Basin using the visual interpolation method. The residual magnetic map was subjected to an upward continuation filter at 2 km, 3 km, 5 km, 7 km, 10 km, and 15 km. The results obtained from the analysis of the total magnetic intensity map (TMI), regional map, residual map, and upward continuation maps showed that the Sokoto basin is shallower in the south and thicker in the north, which borders the Niger Republic. The northeastern region had low magnetic values which could be a sign of higher sedimentations especially in places like Isah, Rabah, Talata/Mafara, and Gandi. Faults trending Northeast-Southwest direction is quite obvious which is common with structures in Nigeria. Most of these faults fall within the regions of heavily dense sedimentation. The most probable zones for the possibility of hydrocarbon accumulation in the area are those with comparatively denser sediments.

KEYWORDS: *Aeromagnetic, Anomaly, Structures, Total Intensity of Magnetism Map, Residual map*

INTRODUCTION

A growing body of evidence suggests that the Pan-African collision was not between the West African craton and the Pan-African belt as a whole, but rather an aggregation of crustal blocks. For ages, people have been concerned about the earth and its contents. Man has used a variety of geophysical techniques to try to understand its origins and unravel

its complexity. Geoscientists have a special interest in the subsurface and look into it using a variety of methods; some do this to learn more, while others do it to explore for valuable resources like minerals and hydrocarbons.

Earth scientists have determined that it is essential to use the properties associated with the earth's interior due to technological advancements and the need

to have a better understanding of the earth's subsurface and its contents. Applying physical principles and quantitative physical measurements to the study of the earth's interior is known as geophysics. The analysis of these measurements can reveal how the earth interior varies both vertically and laterally, and the interpretation of which can reveal meaningful information on the geological structures beneath (Dobrin, 1976). By working at different scales, geophysical methods may be applied to a wide range of investigations from studies of the entire earth to exploration of a localized region of the upper crust for engineering or other purposes (Kearey *et al.*, 2004). Many different geophysical techniques are available, and each one is sensitive to a different physical property. It is evident that a method's range of application is determined by the kind of physical property it responds to. For example, due to their magnetic susceptibility, buried magnetic ore bodies can be found using the magnetic method.

Similarly, seismic and electrical methods are suitable for locating water table, because saturated rock may be distinguished from dry rock by its higher seismic velocity and higher electrical conductivity (Kearey *et al.*, 2004). Local features of potential interest can be identified and delineated using geophysical methods in subsurface resource exploration. Geophysical methods for detecting discontinuities, faults, joints and other basement structures, include the following: magnetics, seismic, resistivity, electrical, potential field, well logging, gravity, radiometric, thermal etc (Corell and Grouch, 1985). Remote sensing and gamma ray spectrometry are two examples of geophysical techniques

that measure surface characteristics. Thermal and some electrical techniques, on the other hand, are only able to detect relatively shallow subsurface geological features. Geophysical modeling provides generalized and no-unique solution to questions concerning the concerning the geometry of the subsurface geologic structures. Oil, gas, groundwater, and the majority of valuable minerals are hidden beneath the surface of the earth and therefore out of direct view. Only by conducting geophysical studies of the region's subsurface geologic structures can the existence and extent of these resources be determined. Estimating the depth of the sediments is essential when studying sedimentary basins for hydrocarbon potentials because the thickness of the basin determines all other requirements for hydrocarbon maturation. Therefore, if the area under investigation has no previous geological information and the primary aim of the study is to search for hydrocarbon deposits; the first question that must be answered, is whether the sedimentary basin is large enough and thick enough to justify any further investigations (Reynolds, 1990). These are additional standards for evaluating a basin for potential hydrocarbon buildup are the source rock, reservoir rock, seal, paleotemperatures, trap. The objective of this study is to carry out geophysical analysis to determine structures that might have served as conduit and/or housed commercial minerals.

MATERIALS AND METHODS

Aeromagnetic data from the Sokoto Basin was used in this study to create residual magnetic maps and total magnetic intensity. Upward continuation techniques were applied to the residual map at

intervals of 2 km, 3 km, 5 km, 7 km, 10 km, and 15 km in order to map out faults and areas of thicker sedimentation that might harbour hydrocarbon deposition.

Study Area

In northwest Nigeria, the Sokoto Sedimentary Basin serves as the study area (Figure 1). With an estimated area of 59,570 km², the Sokoto Basin is located between longitudes 3° 30" E and 6° 58" E and latitudes 10° 20" N and 14° 00" N. The Basin is covered by twenty- nine half-degree aeromagnetic maps (8-13; 26-32; 48- 54; 71-74; 94-97; and 116-119) of the Geology Survey of Nigeria, now renamed the Nigerian Geological Survey Agency (NGSA).

The Sokoto Sedimentary Basin forms the southeastern segment of a large synclinal basin, the Iullemeden basin. The Iullemeden basin (Figure 2) lies entirely with the Pan African province of West Africa; which encompasses parts of Algeria, Mali, and republics of Benin and Niger. The Basin is bounded to the north by the massifs of the Adrar des Iforas, Hoggar and Air regions. To the west, it is connected to the Taoudeni Basin by the Gao trough. To the east the Iullemeden Basin is contiguous with the Chad Basin, through the Damergou area. In the south, the basement rocks of northern Nigeria delimit the Iullemeden basin. The centre of the Iullemeden basin is located north of Niamey in the republic of Niger.

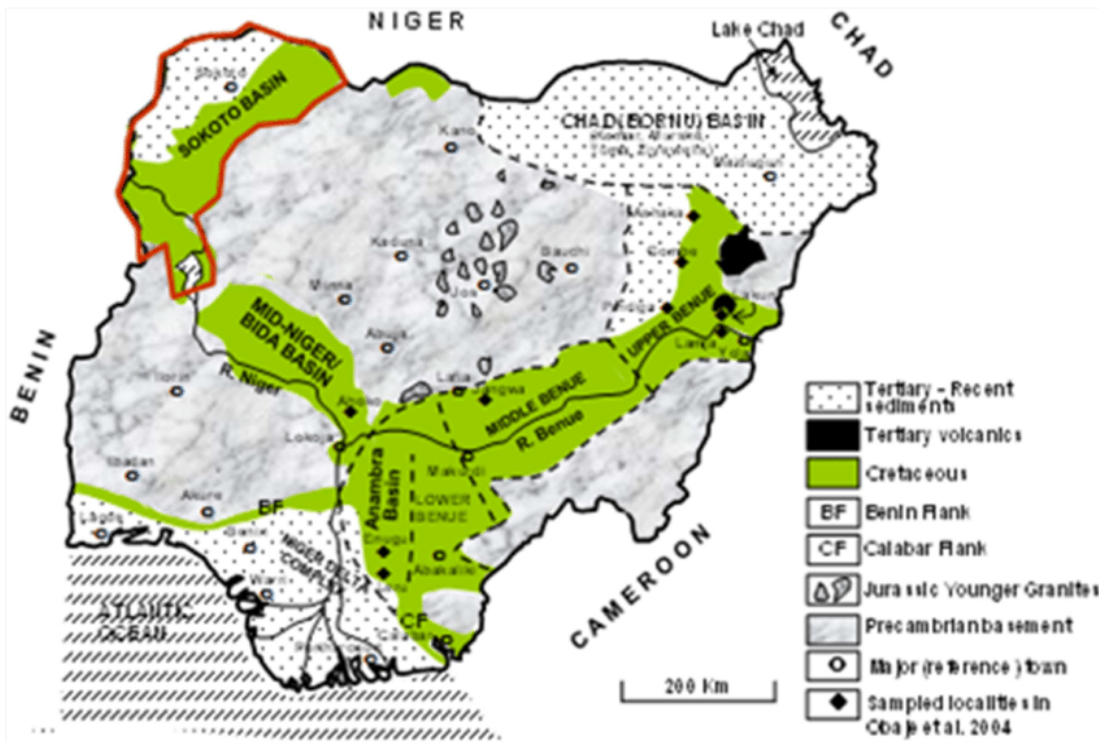


Fig. 1: Sokoto Basin (Nuhu *et al.*, 2020)

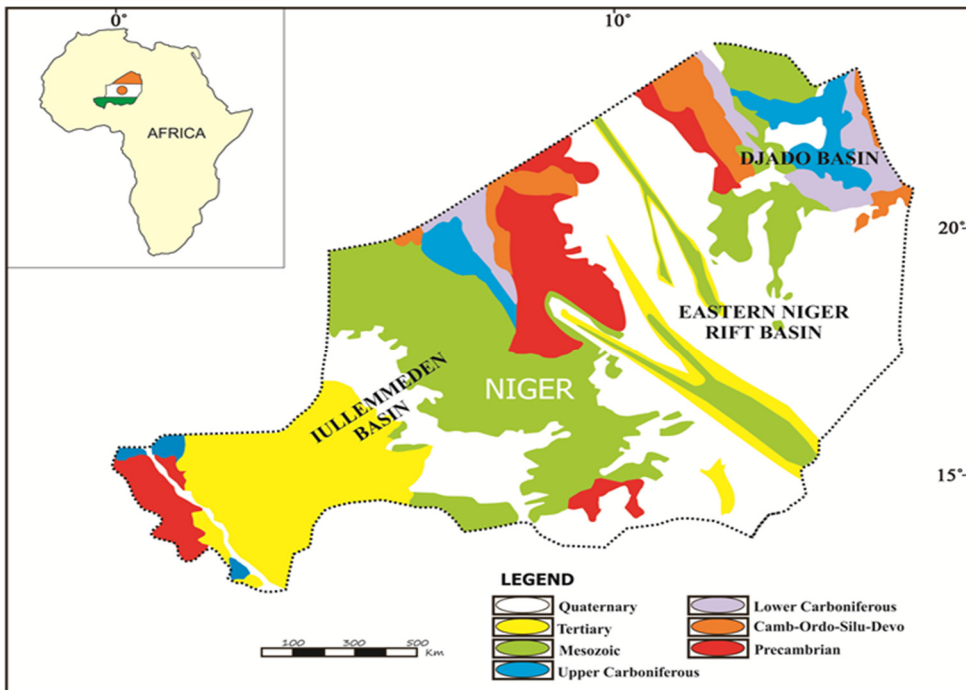


Fig. 2: The Iullemeden Basin (Harouna and Philip, 2012)

The study area is covered by twenty-nine aeromagnetic maps of total field intensity in half –degree sheets. These data were obtained from the Nigerian Geological Survey Agency (NGSA), now renamed the Nigerian Geological Survey Agency (NGSA). Between 1974 and 1980, the Agency conducted a magnetic survey of a significant portion of Nigeria from the air. Flight lines plotted on tape records or a continuous strip chart make up the magnetic information. At a nominal flight altitude of 152.4 meters, the data were gathered along N-S flight lines that were roughly 2 km apart. The magnetic data that was gathered was published as 1:100,000 scale ½ degree aeromagnetic maps. Plotting of the magnetic values was done at 10-nT (nano Tesla) intervals. For convenience and identification, the maps are numbered, with place names and coordinates (longitude and latitude) written on them. Prior to the contour map being plotted, the actual magnetic values

were lowered by 25,000 gamma. This suggests that the actual magnetic field at a specific location can be obtained by adding 25,000 gamma to the contour values. The International Geomagnetic Reference Field (IGRF) and the epoch date of January 1, 1974, were used to correct all of the maps.

Field intensity aeromagnetic maps covering the study area were digitized using the visual interpolation method, which is also known as the Grid Layout method. The longitude, latitude, town name flown, and sheet number are all recorded in a 19 by 19 coding sheet containing the data from each digitized map. After the edge effect was eliminated, the unified composite dataset for the study area was created. To import the data set, Surfer 8 Geosoftware was utilized. Three columns (longitude, latitude, and magnetic values) make up the dataset. Using Oasis Montaj, the composite map was created.

Production of Regional and Residual Maps

By using the Polynomial fitting method to subtract the regional field from the total magnetic field, the residual magnetic field of the study area was generated. To generate the coordinates of the total intensity field data values, the computer program Aero super map was utilized. This super data file, for all the magnetic values was used for production of composite aeromagnetic map of the study area using Oasis Montaj software version 7.2. A program was used to derive the residual magnetic values by subtracting values of regional field from the total magnetic field values to produce the residual magnetic map and the regional map.

Upward Continuation

Upward continuation suppresses the effects of local features, simplifying the appearance of regional magnetic maps. The growth of local magnetic anomalies frequently masks the regional features with too much information. Thus, upward continuation evened out these turbulences without compromising the primary regional characteristics. Viewing the magnetic field intensity at a height above flight level serves the primary function of upward continuation, which emphasizes longer wavelength anomalies that reflect regional features in order to eliminate short wavelength anomalies. The inverse square law of Coulomb governs the earth's total magnetic field.

$$(TMI \propto 1/r^2) \dots\dots 1$$

One can compute a potential field measured at a constant height on a specific observation plane as if the observations had been made on a different plane, either lower (downward continuation) or higher (upward continuation). This is the straightforward equation for the wave number domain filter that generates upward continuation.

$$F = e^{-hw} \dots\dots\dots 2$$

The height of the continuation is denoted by (h). More regional features predominate on this map as a result of the function's steady decay with increasing wave number, which attenuates the height wave numbers more severely. Likewise, the wave number domain filter's equation for generating downward continuation is as follows.

$$F = ehw \dots\dots\dots 3$$

This curve highlights the impact of shallow sources and noise because it is zero at wave number and grows exponentially at higher wavenumbers. Therefore, removing noise is a necessary first step before applying downward continuation, and continuation depths don't go deeper than the actual source depths. Some careful experimentation is usually necessary to obtain acceptable result (Reeves, 2005).

RESULTS

Using Oasis Montaj, this study created a total magnetic intensity map (TMI) of the Sokoto sedimentary basin as shown in Figure 3.

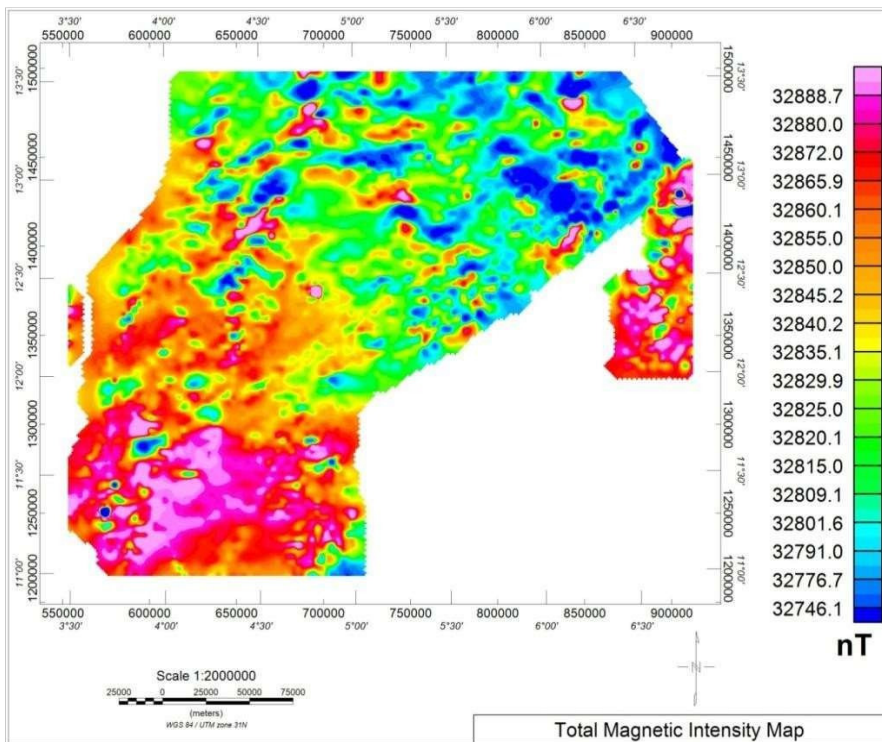


Fig. 3: The total magnetic intensity map (TMI)

The TMI map of the Sokoto sedimentary basin can be separated into three main sections, though there are small depressions throughout the region. Low magnetic intensity values, with a dark-green-blue hue, are indicative of the northern Sokoto basin. In contrast, high magnetic intensity values, denoted by the colour red, predominate in the southern region. The yellow-orange zone, which is defined by medium magnetic intensity values, separates the two sections. The southern portion of the sedimentary basin is dominated by high magnetic intensity values, which are most likely the result of near-surface igneous rocks with high magnetic susceptibilities. Most likely, sedimentary rocks and other non-magnetic sources are the cause of the low amplitudes. Igneous and crystalline basement rocks typically have high magnetic values. Low magnetic

values, on the other hand, are typically found in sedimentary or altered basement rocks. In general, the Sokoto basin's sedimentary thickness. Overall, it seems that the Sokoto basin's sedimentary thickness increases from south to north. This is in good agreement with the results of the 1979 2D seismic surveys that were carried out by the ELF and Mobil Companies. Examining the total magnetic intensity map (TMI) of the study area (Figure 4) reveals no discernible patterns. However, northeast- southwest trend is observed in the north central part of the total magnetic intensity map of the study area. In Ananaba and Ajakaiye (1989); based on lineament of LANDSAT images, identified predominate tectonic trends in the NE –SW, NW-SE directions over the entire basin and in particular over parts of the country rejuvenated during tectonic phase of the pan Africa Orogeny. (Umego,

1990) in a study of aeromagnetic field over the Sokoto basin, identified the existence of NE-SW trending anomalies as the predominant magnetic features in the area. He noted that only NW-SE trending faults were seen near Dange, indicating that the sediments in the

basin had not experienced a substantial amount of faulting (sheet No. 29) as well as Gilbedi villages in the research.

Regional Magnetic Intensity Map

The study area's regional magnetic intensity map (Figure 4) was created with Oasis Montaj.

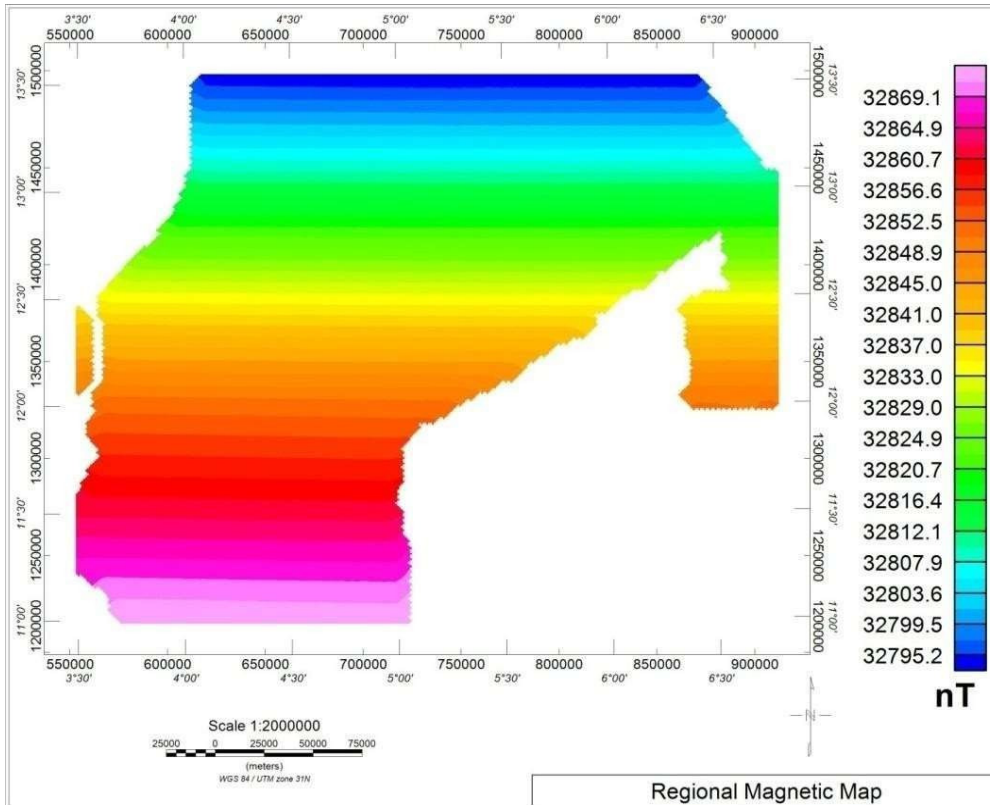


Fig. 4: The regional magnetic intensity map of the study area

Indicating that there is a greater fill of sediments in the northern portion of the basin than in the southern portion of the study area, the regional magnetic values range from 7830 to 7870 nanotesla and decrease from south to north. On the regional map of the study areas, the trend runs from east to west. Deeper earth crust heterogeneity is thought to be the cause of the regional trend. The regional map (Figure 4) and the study's total

magnetic intensity map show good agreement.

Residual Magnetic Intensity Map

Whereas Figure 6 shows the study area's residual magnetic intensity maps from the total magnetic intensity map created with Oasis Montaj, Figure 5 shows the study area's residual magnetic intensity maps from the total magnetic intensity map created with Surfer 8.

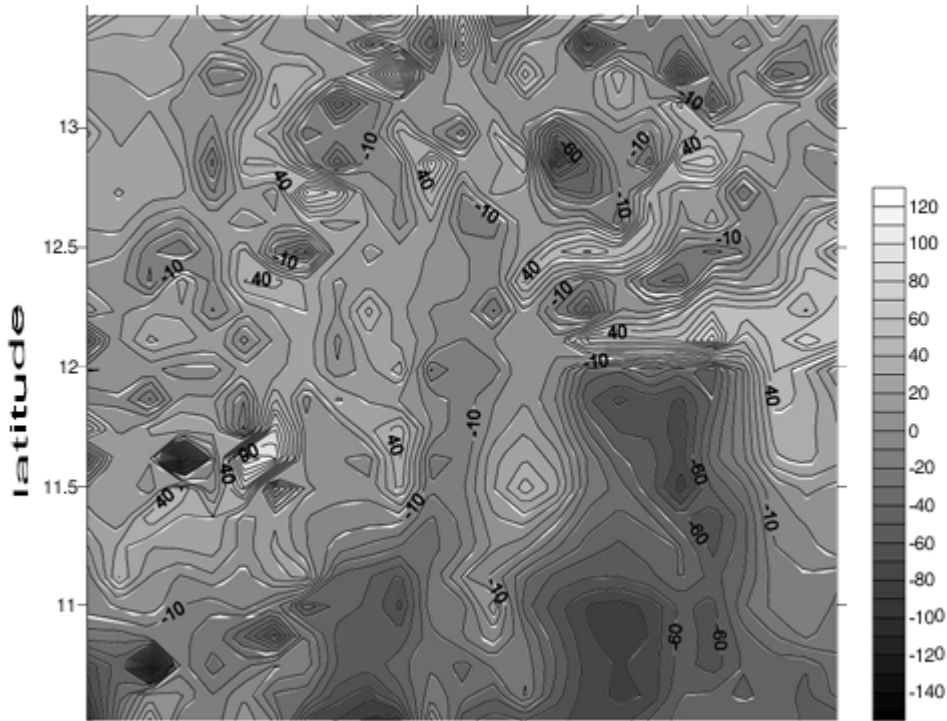


Fig. 5: Residual magnetic intensity maps of the study area (Surfer8)

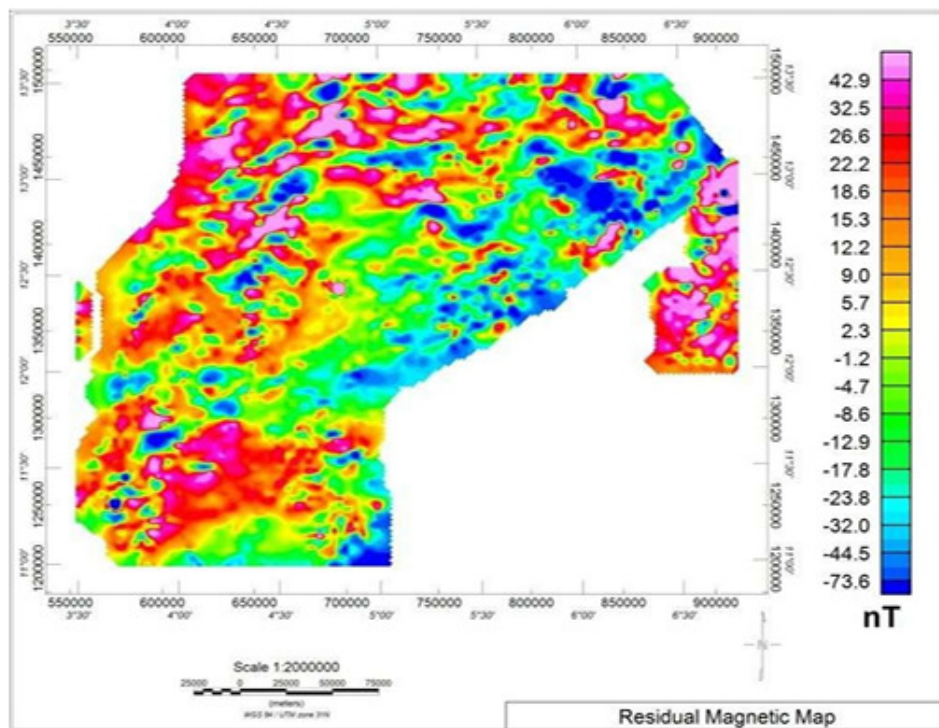


Fig. 6: The residual magnetic intensity maps of the study area

Between 10 and 40 nanoteslas is the range of the magnetic intensity values. In the northern portion of the study area, negative magnetic intensity values are more common, whereas in the southwest, positive magnetic intensity values are more prevalent.

The north central region of the TMI map shows trends from northeast to southwest. ***TMI Upward Continued at 2km***

The total magnetic intensity map of the study area was upward continued at 2 km to produce Figure 7.

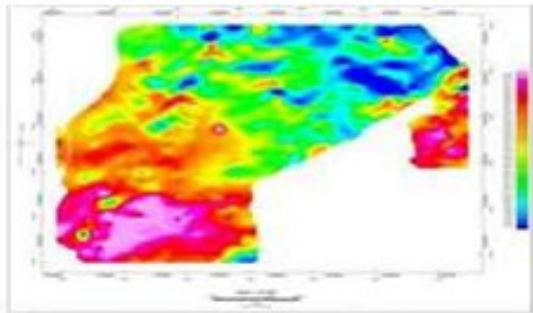


Fig. 7

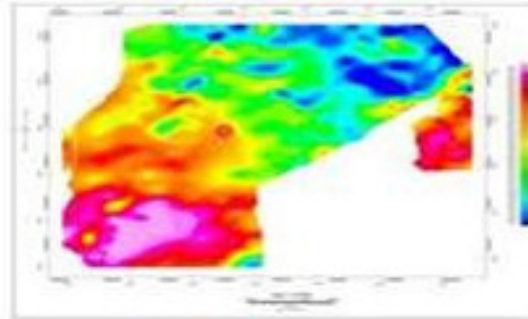


Fig. 8

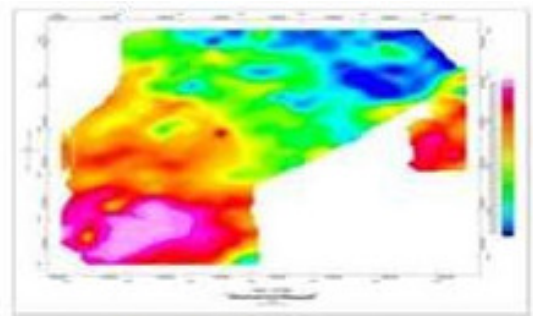


Fig. 9

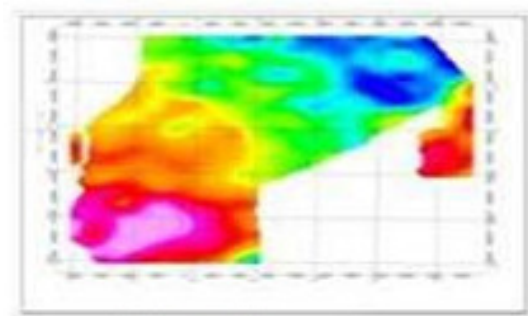


Fig. 10

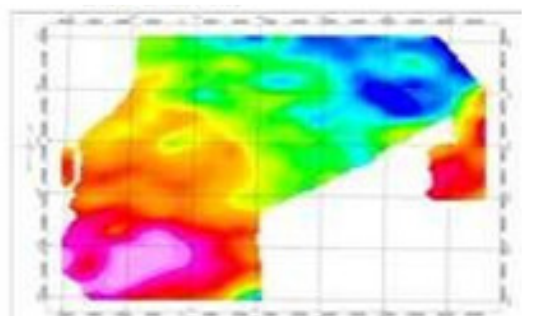


Fig. 11

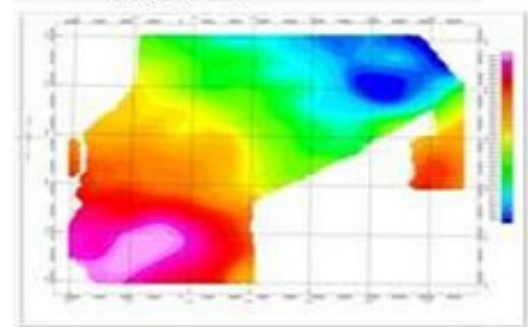


Fig. 12

Although they are not as detailed as the map of total magnetic intensity, the shorter wavelength anomalies can be seen at a height of 2 km. It is possible to see four sections. With only faint hints of green and blue, the bottom half of the map

(latitude $11^{\circ} 00''N$ to $12^{\circ} 00''N$ and longitude $3^{\circ} 30''E$ to $5^{\circ} 00''E$) is primarily pink. In the centre of this section, there is a faint pink hue. A section of yellow with faint traces of green and blue pigments can be found between longitudes $3^{\circ} 30''E$ to 5°

00"E and latitudes 12 °00"N to 13 °30"N. The third section is the region that is delineated by latitudes 12°N to 13°N and longitudes 3°E to 6°E. The predominant colour in this area of the map is green. Around the ranges of latitude 12 °.00"N to 13 °30"N and longitudes 4 ° 30"E to 6 ° 30"E are located in the map's most northern section. In this region, blue and dark-blue hues are common. The study area's highest sedimentary thickness is found in this particular section.

TMI Upward Continued at 3km

Figure 8 displays the map of upward continuation up to 3 km. This figure indicates that the TMI maps at this flight level differ net. In this case, the short wavelength anomalies have started to fade, which has led to the consolidation of longer wavelength anomaly units and their enhancement. Concrete connections between the same anomaly types are distinct and easily observable. We can see that yellow to velvet colour shaded anomalies are on the other hand maturing by enhancing blue colour shaded anomalies. The map can be divided into four sections. At the bottom side of the map (latitude 11° 00"N to 12° 00"N and longitude 3° 30"E to 5° 00"E), is predominantly pink colour with few traces of green and blue colours. A light pink colour is observed in the middle of this portion. Within the range of longitude 3° 30"E to 5° 00"E and latitude 12° 00"N to 13 ° 00"N is a section characterized by yellow colour with few traces of green and blue pigments. Green colour dominates the portion of the map defined by latitude 12 °00"N to 13 °30"N and longitude 3° 30"E to 6° 00"E.

At approximately the ranges of longitude 4 ° 30"E to 6 ° 30"E and latitude 12 °.00"N to 13 °30"N, (at the extreme northern part of the map) blue and dark-

blue colours are prevalent in this area which indicates areas of highest sedimentary thicknesses.

TMI Upward Continued at 5km

The upward continuation of the total magnetic field map at 5 km is shown in Figure 9. The map shows that basement features are standing out at the detriment of shallow sedimentary features. Basement structures and the lineaments in the study area are here well defined because erratic signals are filtered. Fault boundaries between basement and sedimentary areas can be clearly seen. At the bottom side of the map (latitude 11° 00"N to 12° 00"N and longitude 3° 30"E to 5° 00"E), is predominantly pink colour with few traces of green and blue colours. A light pink colour is observed in the middle of this portion. Within the range of longitude 3° 30"E to 5° 00"E and latitude 12° 00"N to 13 ° 00"N is a section characterized by yellow colour with few traces of green and blue pigments. The third section is the area defined by latitude 12 °00"N to 13 °30"N and longitude 3° 30"E to 6° 00"E. Green colour dominates this portion of the map. Areas around bounded by longitude 4 ° 30"E to 6 ° 30"E and latitude 12 °.00"N to 13 °30"N, blue and dark-blue colours are prevalent in this area. This is the section having the highest sedimentary thickness in the study area.

TMI Upward continued at 7km

The map of the upward continuation 7 km height above flight level is shown in Figure 10 At this height, basement structures occupy much more portion of the study area. Low magnetic areas are found to be northern part. The study area's basement structures and lineaments are clearly defined at a depth of 7 km because there are very few erratic signals at this depth. With only faint hints of green and blue, the region surrounding

latitudes $11^{\circ} 00''\text{N}$ to $12^{\circ} 00''\text{N}$ and longitude $3^{\circ} 30''\text{E}$ to $5^{\circ} 00''\text{E}$ is primarily pink. In the centre of this section, there is a noticeable hint of pink. A region that is yellow in colour with faint hints of green and blue pigments lies between longitudes $3^{\circ} 30''\text{E}$ to $5^{\circ} 00''\text{E}$ and latitude $12^{\circ} 00''\text{N}$ to $13^{\circ} 00''\text{N}$. The third section is the region that is delineated by latitudes $12^{\circ} 00''\text{N}$ to $13^{\circ} 30''\text{N}$ and longitude $3^{\circ} 30''\text{E}$ to $6^{\circ} 00''\text{E}$. The predominant colour in this area of the map is green. Around the ranges of longitude $4^{\circ} 30''\text{E}$ to $6^{\circ} 30''\text{E}$ and latitude $12^{\circ} 00''\text{N}$ to $13^{\circ} 30''\text{N}$ are located in the map's most northern section. In the region, blue and dark-blue hues are prevalent. The study area's highest sediments are found in this specific section.

TMI Upward Continued at 10 km

The map of the upward continuation at 10 km height above flight level as shown in Figure 11. At this height, basement structures appeared quite distinct from the sedimentary areas. Areas of lowest magnetic values, (that is areas of thicker deposits of sediments) found to be at northeast part of the study area. The fourth section of this map, particularly the area defined by longitude $5^{\circ} 30''\text{E}$ to $6^{\circ} 30''\text{E}$ and latitude $12^{\circ} 00''\text{N}$ to $13^{\circ} 00''\text{N}$ is large a portion of dark blue colour; clearly an indication of the area having the highest sedimentary thickness in the study area. At the bottom side of the map (latitude $11^{\circ} 00''\text{N}$ to $12^{\circ} 00''\text{N}$ and longitude $3^{\circ} 30''\text{E}$ to $5^{\circ} 00''\text{E}$), is predominantly pink colour with few traces of green and blue colours. A light pink colour is observed in the middle of this portion. The area bounded by longitude $3^{\circ} 30''\text{E}$ to $5^{\circ} 00''\text{E}$ and latitude $12^{\circ} 00''\text{N}$ to $13^{\circ} 00''\text{N}$ is a section characterized by yellow colour with few traces of green and blue pigments. The third section is the area defined by latitude $12^{\circ} 00''\text{N}$ to $13^{\circ} 30''\text{N}$ and longitude $3^{\circ} 30''\text{E}$ to $6^{\circ} 00''\text{E}$. Green colour

dominates this portion of the map. At the extreme northern part of the map, approximately the ranges of longitude $4^{\circ} 30''\text{E}$ to $6^{\circ} 30''\text{E}$ and latitude $12^{\circ} 00''\text{N}$ to $13^{\circ} 30''\text{N}$, blue and dark-blue colours are prevalent in this area. This is the section having the highest sedimentary thickness in the study area.

TMI Upward Continued at 15km

The map of the upward continuation at 15 km height above flight level is shown in Figure 312, at this height, basement structures stood out from the sedimentary regions. It was discovered that the northeastern portion of the study area had the lowest magnetic values, which correspond to areas with thicker sediment deposits. The fourth section of this map, particularly the area defined by longitude $5^{\circ} 30''\text{E}$ to $6^{\circ} 30''\text{E}$ and latitude $12^{\circ} 00''\text{N}$ to $13^{\circ} 00''\text{N}$ is large portion of dark blue colour; clearly and indication of the area having the highest sedimentary thickness in the study area. This region can be found on sheets 11 (Rabah) and 12 (Isah) of the Nigerian index map comparison.

DISCUSSION

A close examination of the maps showing downward continuation at depths of 2 km, 3 km, 5 km, 7 km, and 10 km makes it evident that the shallow effect of the magnetic anomalies causes the disturbances (noises) to gradually disappear, enhancing the regional effects in a distinctive way. Generally speaking, the northern portion of the study area has low magnetic values, which could be a sign of deep-seated anomalies or thicker sediments in the area. Figures 11 and 12 clearly illustrate the regional effects, and the maps trend-wise resemble the regional map and the map of the total magnetic intensity of the study area.

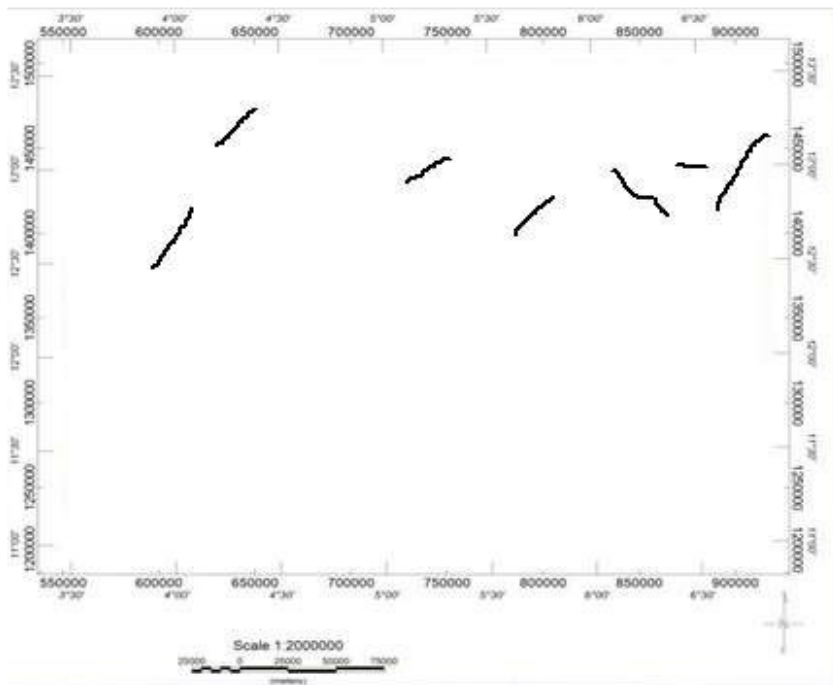


Figure 3.12 Map of the area showing structures which lie close to the heavily sedimented areas.

As seen in figure 3.12, faults trending Northeast-Southwest direction is quite obvious which is common with structures in Nigeria (Ohioma and Ikponmwen, 2020; Ohioma *et al.*, 2019). Most of these faults fall within the regions of heavily dense sedimentation.

CONCLUSION

The Sokoto basin is shallower in the south and thicker in the north, which borders the Niger Republic, according to the analysis of the total magnetic intensity map (TMI), regional map, residual map, and upward continuation maps at 2 km, 3 km, 5 km, 7 km, 10 km, and 15 km. The results of the upward continuation showed that the areas with the highest sedimentation in the study area were Rabah, Isah, Gandi, and Mafara. The result collaborates with those obtained by other researchers that conducted studies in some sections of the basin; notably are

results of studies by (Umego, 1990; Adetona *et al.*, 2007; Uwah, 1984; Udensi, 2013; Bonde *et al.*, 2014). The continuation map shows that the study area has few faults, the majority of which trend NE-SW. The most probable zones for the possibility of hydrocarbon accumulation in the area are those with comparatively denser sediments.

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