

Delineation of Magnetic Zones of Sokoto Basin, in Northwestern Nigeria, Using Aeromagnetic Data.

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ABSTRACT: The Sokoto Sedimentary Basin in northwestern Nigeria, is situated between latitudes 10° 30" N to 14° 00" N and longitude 3° 30" E to 7° 00" E with an estimated area of 59,570 km². We used visual interpolation method to digitized twenty nine aeromagnetic maps of the Basin, the data obtained was used to produce the Total Magnetic Intensity and the Residual Maps. The Residual Magnetic Map was subjected to Upward continuation techniques; applied at 2km, 3km, 5km, 7km, 10km and 15km. The results of the studies delineated areas of higher sedimentations such as Isah, Rabah, Talata/Mafara and Gandi in the northeastern part of the area. These areas of relatively thicker sediments, identified in this study, are therefore the most probable sites for prospect of hydrocarbon accumulation in the area.

KEYWORDS: Magnetic Anomaly, Total magnetic Intensity Map, Residual map.

I. INTRODUCTION

The earth and its contents have long been of concern to mankind. Man has tried to unravel its complexity and delve into its origin via various geophysical methods. The subsurface has been of particular concern to geoscientists, who seek to investigate it using diverse means, some for the purpose of having knowledge, while others do it for exploration of economic resources such as minerals and hydrocarbons. With the advances in technology and the need to have a clearer picture of the earth subsurface and its contents, the earth scientists have deemed it necessary to utilize the properties associated with earth's interior. Geophysics involves the application of physical principles and quantitative physical measurements in order to study the earth's interior. 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). A wide range of geophysical methods exist for each of which there is an operative physical property to which the method is sensitive. The type of physical property to which a method responds clearly determines its range of application.

Thus, for instance, magnetic method is very suitable for locating buried magnetic ore bodies because of their magnetic susceptibility. 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). In exploration for subsurface resources, the geophysical methods are capable of detecting and delineating local features of potential interest. 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 Grauch, 1985). Some geophysical methods such as gamma-ray spectrometry and remote sensing measure surface attributes; others, such as thermal and some electrical methods are limited to detecting relatively shallow subsurface geological features. Geophysical modeling provides generalized and no-unique solution to questions concerning the geometry of the subsurface geologic structures (Reeves, 2005). Most economic minerals, oil, gas, and groundwater lie concealed beneath the earth surface, thus hidden from direct view. The presence and magnitude of these resources can only be ascertained by geophysical investigations of the subsurface geologic structures in the area. In study of sedimentary basins for hydrocarbon potentials; depth estimation of the sediments is very crucial because all other necessary conditions for hydrocarbon maturation depend on the thickness of the basin. 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). Other criteria for assessing a basin for possible hydrocarbon accumulation are as follows:

- **Source rock:** The presence of a source rock with adequate organic materials of various types determines whether oil or gas will be sourced in the process of hydrocarbon generation.
- **Reservoir rock:** Reservoir rock ensures that hydrocarbon generated are accommodated in pore spaces that exists between the grains in the subsurface.
- **Seal:** seals are normally without pore spaces ensures that hydrocarbon generated in the reservoir rocks are kept in place and prevented from migrating to the surface and subsequent loss.
- **Paleotemperatures:** Paleotemperatures or ancient Paleotemperatures are responsible for generation of hydrocarbon from organic matter.
- **Trap:**The trap ensures that oil sealed in place does not migrate and be lost.

In this study, aeromagnetic data of Sokoto Basin was used to produce total magnetic intensity and residual magnetic maps of the basin. The residual map was subjected to Upward continuation techniques; applied at 2km, 3km, 5km, 7km, 10km and 15km to delineate areas of higher sedimentation which might favor accumulation of hydrocarbon..

1.1 The study area

The study area is the Sokoto Sedimentary Basin, in northwestern Nigeria (Figure1.1).The Sokoto Basin lies between longitudes 3°30"E and 6°58"E and latitudes 10° 20"N and 14° 00"N with an estimated area of 59,570 km².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)*.

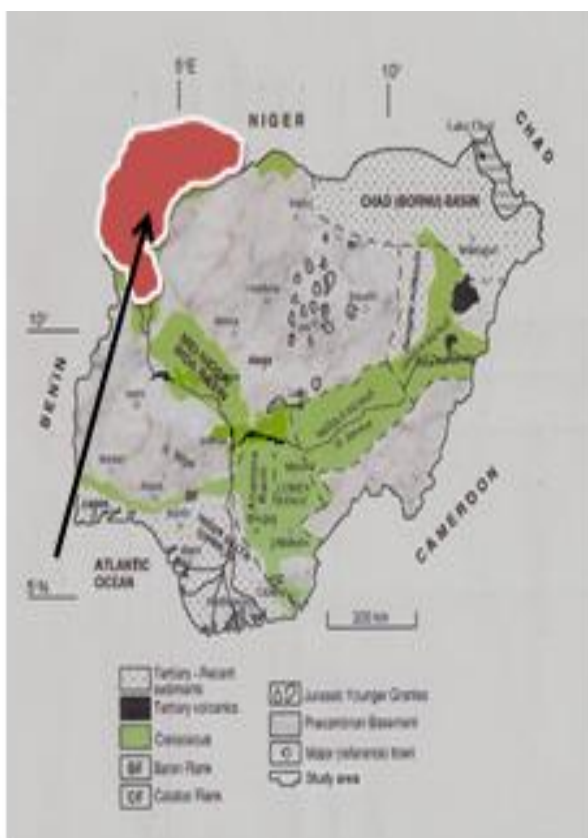


Figure1.1 Sokoto Basin

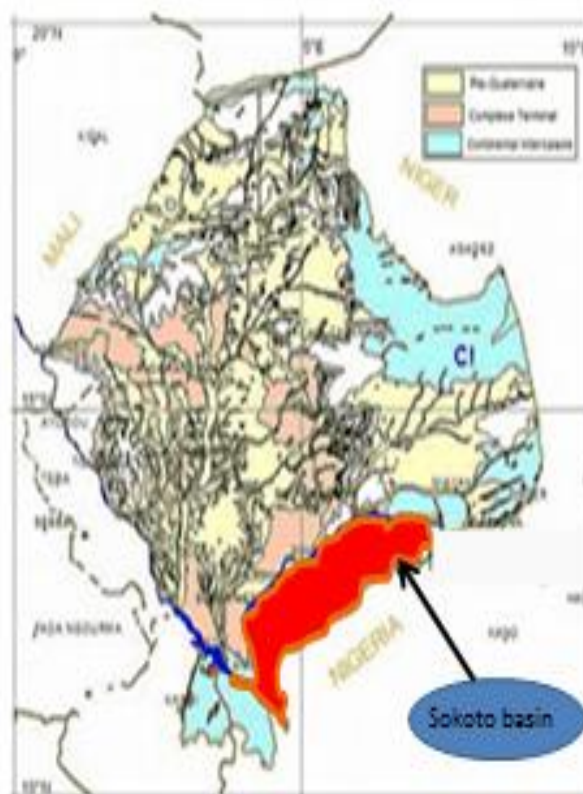


Figure1.2 The Iullemmmeden Basin

The Sokoto Sedimentary Basin forms the southeastern segment of a large synclinal basin, the Iullemmmeden basin. The Iullemmmeden basin (Figure 1.2) 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 Iullemmmeden Basin is contiguous with the Chad Basin, through the Damergou area. In the south, the basement rocks of northern Nigeria delimit the Iullemmmeden basin. The center of the Iullemmmeden basin is located north of Niamey in the republic of Niger.

1.2 Aim and objectives of the study

The aim of the present study is to apply upward continuation techniques on the residual magnetic intensity map of Sokoto sedimentary basin with a view of delineating magnetic zones

The objectives of the study include the following:

- To delineate magnetic zones in sokoto basin using upward continuation techniques.
- To determine the economic potentials of the basin in terms of hydrocarbon prospects.
- The study would generate and upgrade the existing geophysical database of the study area.

II. MATERIALS AND METHODS

The study area is covered by twenty nine aeromagnetic maps of total field intensity in half –degree sheets. These maps are obtained from the Nigerian Geological Survey Agency (NGSA), now renamed the Nigerian Geological Survey Agency (NGSA)).The Agency carried out an airborne magnetic survey of substantial part of Nigeria between 1974 and 1980. The magnetic information consists of flight lines plotted on a continuous strip chart or tape records. The data were collected at a nominal flight altitude of 152.4m along N-S flight lines spaced approximately 2 km apart. The magnetic data collected were published in the form ½ degree aeromagnetic maps on a scale of 1:100,000. The magnetic values were plotted at 10nT (nano Tesla) interval. The maps are numbered, and names of places and coordinates (longitude and latitudes) written for easy reference and identification. The actual magnetic values were reduced by 25,000gamma before plotting the contour map. This implies that the value 25,000 gamma is to be added to the contour values so as to obtain the actual magnetic field at a given point. A correction based on the International Geomagnetic Reference Field, (IGRF,) and epoch date January 1, 1974 was included in all the maps.

The visual interpolation method,that is the method of digitizing on Grid Layout was used to obtain the data from field intensity aeromagnetic maps covering the study area. The data from each digitized map is recorded in a 19 by 19 coding sheet which contains the longitude, latitude and the name of the town flown and the sheet number. The unified composite dataset for the study area was produced after removing the edge effect. Surfer 8 Geosoftware was used to import the data set. The dataset consists of three columns (longitude,latitude and magnetic values). The composite map was produced using Oasis Montaj..

2.1 Production of Regional and Residual Maps

The residual magnetic field of the study area was produced by subtracting the regional field from the total magnetic field using the Polynomial fitting method. The computer program Aerosupermap was used to generate the coordinates of the total intensity field data values. 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.

2.2Upward Continuation

Upward continuation is used in order to simplify the appearance of regional magnetic maps by suppressing the effects due to local features. The proliferation of local magnetic anomalies often obscures the regional features with an overabundance of detail. Upward continuation thus smoothed out these disturbances without impairing the main regional features.The main purpose of upward continuation is to view the magnetic field intensity at a height above flight level so as to eliminate short wavelength anomalies by emphasizing longer ones reflecting regional features. The total magnetic field of the earth obeys coulomb’s inverse square law

$$(TMI \propto 1/r^2) \qquad 2.1$$

it falls off rapidly with height r .

A potential field measured on a given observation plane at a constant height can be calculated as though the observations were made on different plane, either higher (upward continuation) or lower (downward continuation).

The equation of the wave number domain filter to produce upward continuation is simply:

$$F = e^{-hw} \qquad 2.2$$

Where (h) is the continuation height.

This function decays steadily with increasing wave number, attenuating the height wavenumbers more severely, thus producing a map in which more regional features predominate.

Similarly the equation of the wave number domain filter to produce downward continuation is:

$$F = ehw \quad 2.3$$

This is a curve, which is zero at wave number and increases exponentially at higher wavenumber, thus emphasizing the effect of shallow sources and noise. Noise removal is therefore an essential first step before downward continuation is applied, and continuation depths should not exceed real source depths.

Some careful experimentation is usually necessary to obtain acceptable result (Reeves, 2005).

III. RESULTS AND ANALYSIS

The total magnetic intensity map (TMI) of the Sokoto sedimentary basin produced from this study using Oasis Montaj is as shown in Figure 3.1.

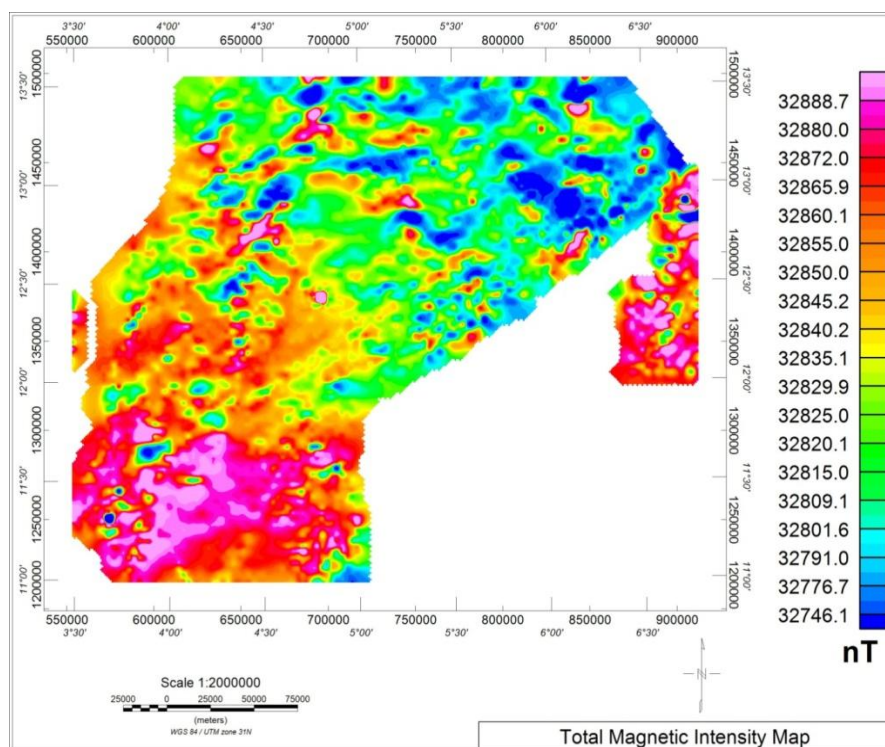


Figure 3.1 The total magnetic intensity map (TMI)

The TMI map of Sokoto sedimentary basin can be divided into main three sections, though minor depressions exist scattered all over area. The northern part of the Sokoto basin is characterized by low magnetic intensity values represented by dark-green-blue color. Whereas the southern part is dominated by high magnetic intensity values indicated by red color. The two sections are separated by a zone characterized by medium magnetic intensity values area depicted by yellow-orange color. These high magnetic intensity values, which dominate the southern part of the Sedimentary basin are caused probably by near surface igneous rocks of high values of magnetic susceptibilities. The low amplitudes are most likely due to sedimentary rocks and other non-magnetic sources. In general, high magnetic values arise from igneous and crystalline basement rocks. Whereas low magnetic values are usually from sedimentary rocks or altered basement rocks. The sedimentary thickness of the Sokoto basin in general, appears to increases from south to north. This collaborates well with earlier findings of 2D Seismic surveys conducted by ELF and Mobil Companies carried out in 1979. Inspection of the total magnetic intensity map (TMI) of the study area(Figure 3.1)does not show any general or particular trend. However, northeast- southwest trend is observed in the north central part of the total magnetic intensity map of the study area. 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 observed that the sediments in the basin were not subjected to a

remarkable degree of faulting as only NW-SE trending faults have been observed in the vicinity of Dange(sheet No.29) and Gilbedi villages within the study.

3.1 Regional Magnetic Intensity Map

The regional magnetic intensity map of the study area (Figure 3.2) produced using Oasis Montaj.

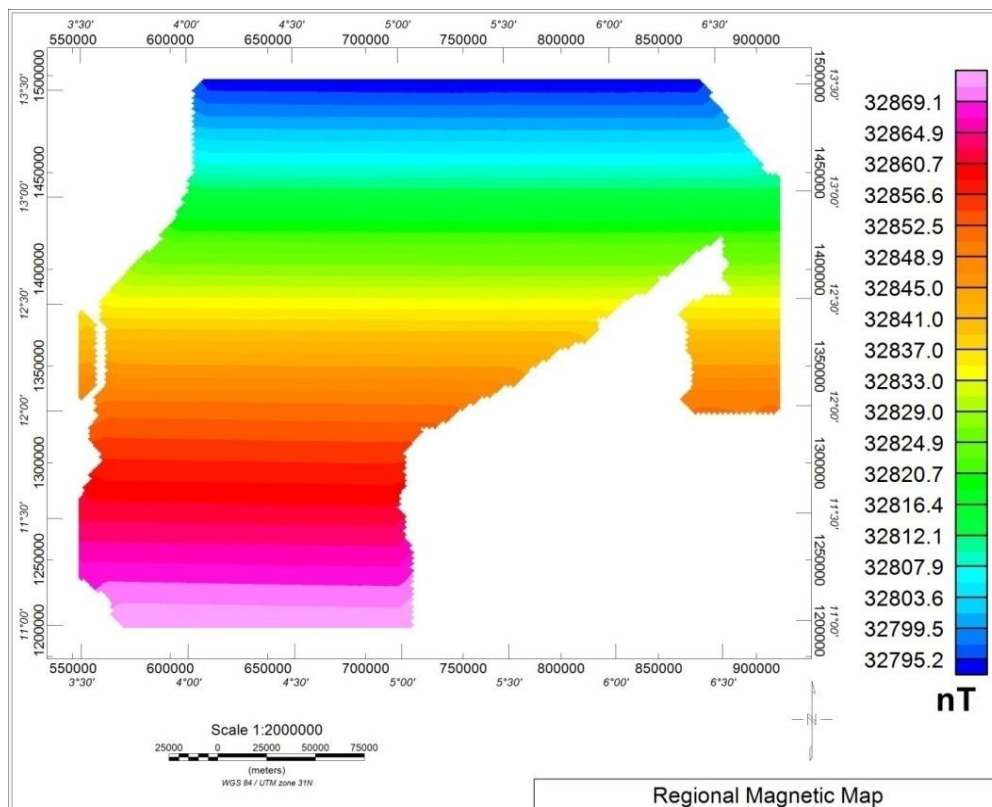


Figure 3.2 The regional magnetic intensity map of the study area.

The regional magnetic values ranges from 7830nano tesla to 7870nano tesla and the values decreases from south to north indicating there is a fill of sediments more in the northern part of the basin than in the southern part of the study area. The trend of the regional map of the study areas is in the east-west direction. The regional trend is attributed to effects of deeper heterogeneity of the earth crust. The regional map (Figure 3.2) agrees well with the total magnetic intensity map obtained from the study.

3.2 Residual Magnetic Intensity Map

Figure 3.3 is the residual magnetic intensity maps of the study area obtained from the total magnetic intensity map produced using Surfer 8, while Figure 3.4 the residual magnetic intensity maps of the study area obtained from the total magnetic intensity map produced using a Oasis Montaj.

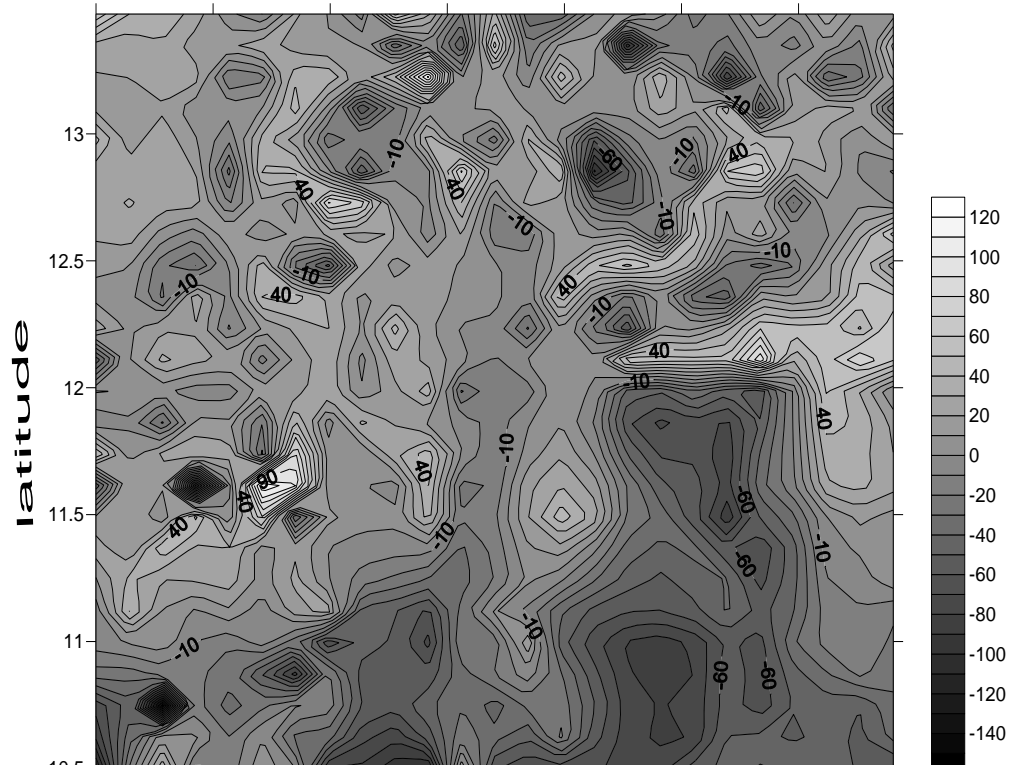


Figure 3.3 the residual magnetic intensity maps of the study area(Surfer8)

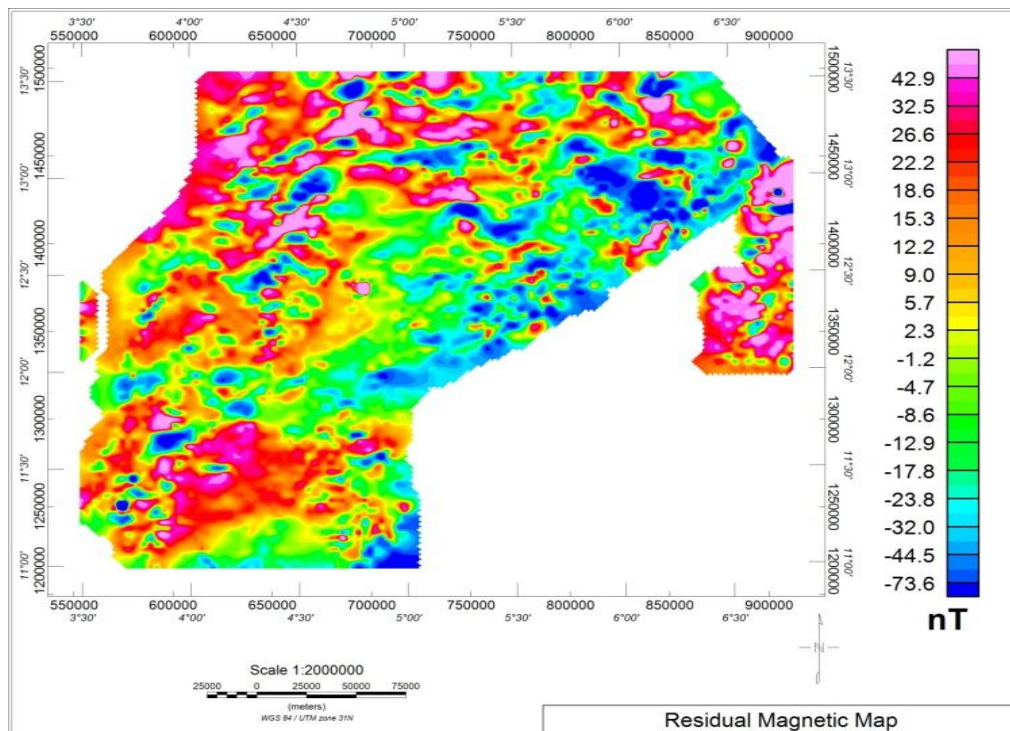


Figure 3.4 the residual magnetic intensity maps of the study area(Oasis Montaj)

The magnetic intensity values ranges from -10 nano tesla to 40 nano tesla. Negative magnetic intensity values are more predominant in the northern section of the study area while the southwest has more of positive magnetic intensity values. Northeast –Southwest trends are observed in the north central part of the TMI map.

3.3 TMI Upward continued at 2km

The total magnetic intensity map of the study area was upward continued at 2 km to produce Figure 3.6 At the height of 2 km, the shorter wavelength anomalies are visible, though slightly refined than the total magnetic intensity map. Four sections can be observed. 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 color with few traces of green and blue colors. A light pink color 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 color 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 color dominates this portion of the map. At the extreme northern part of the map, approximately the ranges of longitude 4° 30"E to 6° 30"E and latitude 12° .00"N to 13° 30"N, blue and dark- blue colors are prevalent in this area. This is the section of the study area having the highest sedimentary thickness.

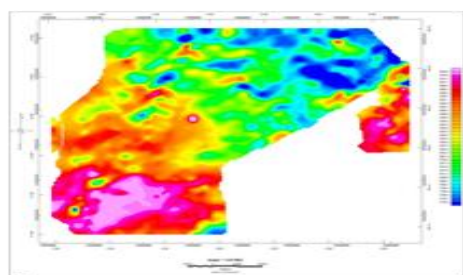


Figure 3.6 at 2km

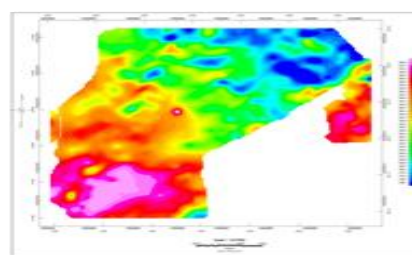


Figure 3.7 at 3km

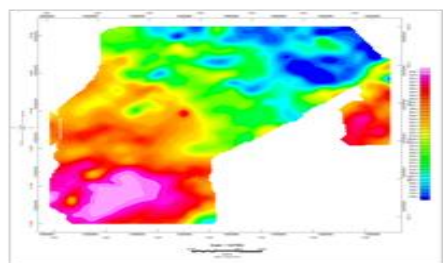


Figure 3.8 5km

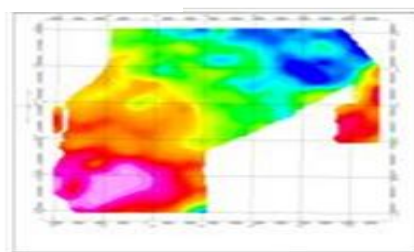


Figure 3.9 7km

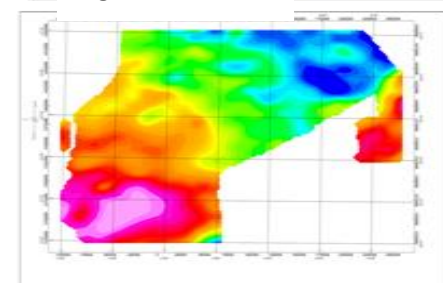


Figure 3.10 10km

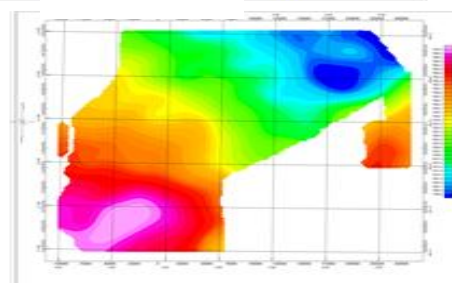


Figure 3.11 15km

TMI Upward continued at 3km

The map of upward continuation to 3 km is shown in Figure 4.7 This figure shows that there is a net difference between the TMI maps at this flight level. Here, the short wavelength anomalies have begun disappearing thereby consolidating longer wavelength, anomaly units are getting enhanced. Concrete links between same anomaly types are clearly visible and distinct. We can see that yellow to velvet color shaded anomalies are on the other hand maturing by enhancing blue color 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 color with few traces of green and blue colors. A light pink color 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 color with few traces of green and blue pigments. Green color 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 colors 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 4.8. 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 color with few traces of green and blue colors. A light pink color 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 color 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 color 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 colors 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 4.9. At this height, basement structures occupy much more portion of the study area. Low magnetic areas are found to be northern part. At 7 km depth, the erratic signals are very minimal, hence basement structures and lineaments in the study area are here well defined at this depth. Around the areas bounded by latitude 11°00'N to 12°00'N and longitude 3°30'E to 5°00'E, is predominantly pink color with few traces of green and blue colors. A light pink color is noticeable 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 color 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 color dominates this portion of the map. At the extreme northern part of the map, approximately the ranges of longitude 4°30'E to 6°30'E and latitude 12°00'N to 13°30'N, blue and dark-blue colors are common in the area. This particular section of the study area shows the highest sediments.

TMI Upward continued at 10 km

The map of the upward continuation at 10 km height above flight level is shown in Figure 4.10. At this height, basement structures appeared quite distinct from the sedimentary areas. Areas of lowest magnetic values, (i.e. 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°30'E to 6°30'E and latitude 12°00'N to 13°00'N is large portion of dark blue color; clearly an indication of the area having the highest sedimentary thickness in the study area. 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 color with few traces of green and blue colors. A light pink color is observed in the middle of this portion. The area bounded by longitude 3°30'E to 5°00'E and latitude 12°00'N to 13°00'N is a section characterized by yellow color 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 color dominates this portion of the map. At the extreme northern part of the map, approximately the ranges of longitude 4°30'E to 6°30'E and latitude 12°00'N to 13°30'N, blue and dark-blue colors 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 4.11. At this height, basement structures appeared quite distinct from the sedimentary areas. Areas of lowest magnetic values, (i.e. 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°30'E to 6°30'E and latitude 12°00'N to 13°00'N is large portion of dark blue color; clearly an indication of the area having the highest sedimentary thickness in the study area. This area is found to be in sheets numbers 11 (Rabah) and 12 (Isah) of the index map of Nigeria. Comparison and close observation of the maps of downward continuation at depths of 2 km, 3 km, 5 km, 7 km and 10 km clearly show progressive disappearance of disturbances (noises) due to the shallow effect of the magnetic anomalies, thereby enhancing the regional effects distinctively. The northern part of the study area is generally characterized with low magnetic values, an indication of either thicker sediments in the

region, or deep seated anomalies. Figures 3.10 and 3.11 clearly show the regional effects and the maps trend wise resembles the total magnetic intensity map as well as the regional map of the study area.

IV. CONCLUSION AND RECOMMENDATIONS

The analysis of the total magnetic intensity map (TMI), the regional map, the residual map, the upward continuation maps at 2km, 3km, 5km, 7km, 10km and 15km of Sokoto basin, all indicate that the basin is shallower in the south and thicker in the north which borders with Niger Republic Upward continuation results delineated Rabah, Isah, Gandi and Mafara areas having highest sedimentation in the study area. 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) and Udensi (2013). Exploration of the Nigerian inland basins is worth given a push. Hydrocarbons if discovered and harnessed findings will increase the country's reserve and boost productivity. All these will have economic and strategic benefits for the country. There is therefore the need to take advantage of modern geophysical methods in the exploration of Nigerian inland basins.

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