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## ASSESSMENT OF HYDROCARBON POTENTIAL THROUGH UPWARD CONTINUATION ANALYSIS OF AEROMAGNETIC DATA: A CASE STUDY OF THE NORTHEASTERN PART OF THE SOKOTO BASIN, NIGERIA

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### Abstract

*Analysis of high-resolution aeromagnetic data was carried out to determine the trend of magnetic zones for hydrocarbon potential in the northeastern part of the Sokoto Basin, Nigeria. The study area is located between longitudes 5°00'E to 6°00'E and latitudes 12°30'N to 13°30'N, covering four (4) map sheets: Sheet 11, 12, 30, and 31, representing Rabah, Isa, Dange, and Mafara, respectively. The total magnetic intensity (TMI) map covering the area was processed and filtered to obtain the residual anomaly map. Upward continuation filters were applied to the residual map to enhance magnetic zones within the area. The total magnetic intensity map indicates that the sedimentary thickness of the northeastern part of the Sokoto Basin generally increases from south to north. The results of the upward continuation at different heights revealed that high sedimentation is concentrated in the northeastern part, particularly around the Isa area. Conversely, high magnetic values, likely due to igneous intrusions, predominate in the southwestern part of the maps. The trend of the magnetic zones decreases from the southwest (SW) to the northeast (NE) direction. This pattern indicates that the northeastern part of the study area represents the deepest section of the basin and is therefore considered a potential site for hydrocarbon accumulation.*

**Keywords:** Geomagnetic field, upward continuation, sedimentation area, magnetic susceptibility, hydrocarbon potential

### Introduction

Earth's magnetic field, also known as the geomagnetic field, is the magnetic field that extends from the Earth's interior out into space, where it interacts with the solar wind (a stream of charged particles emanating from the Sun). The magnetic field is generated by electric currents due to the motion of convection currents of molten iron in the Earth's outer core, these convection currents are caused by heat escaping from the core through a natural process called a geo-dynamo, the earth's outer core is a good conductor of electricity and a fluid in which motion can take place i.e it permits both mechanical motion and the flow of electric current

and the interaction of these could generate a self-sustaining magnetic field (Finlay *at. el.*, 2010).

According to the spherical harmonic analysis of the earth's magnetic field conducted at the surface of the earth, it was revealed that the source of the earth magnetic field is predominantly internal. According to the dynamo theory of the earth's magnetic field; the field of the earth is ultimately produced and maintained by an induction process, the magnetic energy being drawn from the kinetic energy of the fluid motions in the outer core. (Jacob, 1967; Stephen & Iduma, 2018). Geophysical investigations and methods have played very significant roles in the development of the world economy. This is as a result of the improvements on the investigations and methods in terms of their instrumentation, and also the modern ways of interpretation techniques. Nigeria, like other countries in the world adopt the use of geophysics for geological mapping, the Geological Survey of Nigeria (GSN) now Nigerian Geological Survey Agency (NGSA) was given responsibility for the airborne magnetic surveying of the country and the publication of the airborne geophysical map series. Geophysical investigations of this type are extended to provide geologic information which will perhaps stimulate and also assist in a mineral exploration programs. The geophysical methods include magnetic, gravity, electrical and seismic methods, among others.

### **Magnetic Method**

The magnetic method of applied geophysics is the oldest exploration method and depends upon measuring the anomalies of the local geomagnetic field produced by variations in the intensity of magnetization in rock formations which is related to the distribution of magnetic minerals within the rocks over which the field was measured. Magnetic anomaly maps generally reflect variations in the earth's magnetic field resulting from the underlying rocks, magnetic properties such as magnetic susceptibilities among others (Ishaku, 2000). Though most rock forming minerals have negligible to very low magnetic susceptibility and therefore are essentially non-magnetic but certain types of rocks contain enough magnetic minerals they therefore generate recognizable magnetic anomalies. Sedimentary rocks generally have the lowest magnetic susceptibility, whereas metamorphic and basic igneous rocks have the highest magnetic susceptibilities (Kearey *et al.*, 2002). Magnetic anomalies are caused by magnetic minerals contained in rocks; such anomalies are usually associated with underlying basement (igneous and/or metamorphic) rocks or by igneous bodies within sedimentary successions such as intrusive plugs, dykes, sills, lava flows and volcanic rocks (Gunn, 1997), as well as due to cultural iron contamination and antigenic alterations in sedimentary rocks possibly caused by hydrocarbon migration (Costanzo-Alvarez *et al.*, 2000; Aldana *et al.*, 2003).

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## Aeromagnetic Survey

Aeromagnetic survey involves fixing of magnetic field measuring device (magnetometer) to an aircraft and using it to fly over the area of interest at a particular height and at a particular space called line spacing. The aircraft flies in a grid-like pattern and the height and line spacing determining the resolution of the data. As the aircraft is flown across the area, the magnetometer measures the variations in the earth magnetic field due to the temporal effects of the constantly varying solar wind and spatial variations in the Earth's magnetic field. These variations are used for the production of the aeromagnetic map of the area. This map shows the magnetic anomalies originating from the materials within the earth subsurface. The interpretation of aeromagnetic maps involves interpreting the basement structures and detailed examination of structures and lithological variations in the sedimentary section.

## Location of the Study Area

The study area lies between longitude  $5^{\circ}00'00''\text{E}$  to  $6^{\circ}00'00''\text{E}$  and latitude  $12^{\circ}00'00''\text{N}$  to  $13^{\circ}30'\text{N}$ , covering four (4) sheets which are; sheet 11, sheet 12, sheet 30 and sheet 31 representing Rabah, Isa, Dange and Mafara respectively. Several researches were conducted in the basin to show the trends of its magnetic zones for the investigation of its hydrocarbon potentials. Some of these researches include that of Shehuet *al.*, (2004), Adetonaet *al.*, (2007), Ofor and Udensi, (2014), Sambo (1994), Bonde *et al.*, (2014), Ofohaet *al.*, (2016) and Stephen and Iduma (2018).

The objective of this research work is to show the trends of the magnetic zones of the study area for further investigation on the hydrocarbon potential of the area.

## Materials and Method

Four digitized aeromagnetic maps (sheets 11, 12, 30, and 31) representing Rabah, Isa, Dange, and Mafara respectively are used for this research, these maps were obtained from Nigeria Geological Survey Agency (NGSA) and were assembled to obtain one block, referred to as northeastern part of Sokoto Basin in this work. A computer program Oasis Montaj version 7.2 was used to provide the total magnetic intensity map TMI of the study area. In the production of the TMI the single map of the study area obtained was gridded and the grid was then saved into database and new coordinates were projected to change the current coordinates of the grid from x and y in meters (m) to latitude and longitude in degree. The data base was again re-gridded and transported into Oasis montaj software to produce the total magnetic intensity (TMI) map of the study area.

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The TMI (Figure 2) obtained consist of both magnetic effects due to the long wavelength anomalies of the regional field components, which is attributed to deep and large scale sources and the shorter wavelength anomalies constituting the residual field, which is attributed to the shallow and small scale magnetic bodies. Due to the nature of this research residual magnetic anomaly map was used for subsequent investigation. 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. A computer programed Oasis Montaj software version 7.2 was used to derive the residual magnetic values by subtracting values of regional field from the total magnetic field values which produce the residual magnetic map (Figure 1).

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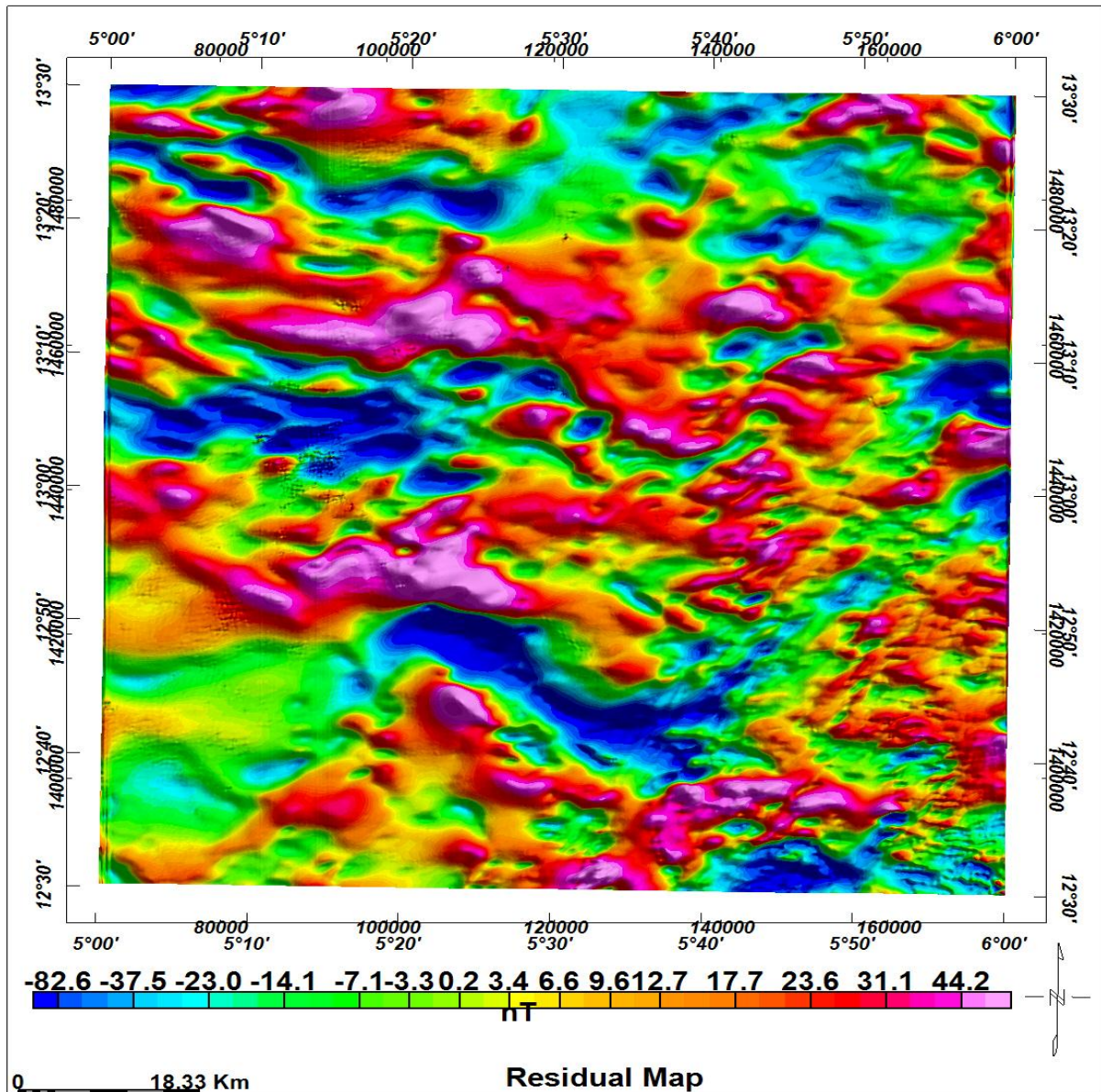


Figure 1 the residual map of the study area

### Upward Continuation:

This is the process of transforming potential field data measured on a surface to some other higher surface (Akoet *al.*, 2004) it is used as a filter to reduce the effect of near surface bodies in order to emphasize anomalies from deep features. Since the data are being ‘ moved ’ away from the source, this procedure is generally stable mathematically using Fourier domain algorithms by applying inverse Fourier transforms carried out in the Fourier domain.

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$$\text{TUC}^{(u,v)} = e^{-z/k/}$$

$$\text{But/K/} = (U^2 + V^2)$$

Where  $u$  and  $v$  represent  $x$  and  $y$  wave numbers and  $z$  is the continuation height. These operations are carried out in the space domain. In this research work the residual map was subjected to upward continuation technique at 5, 10, 15, 20, 25, 30, 35, 40 and 45 km to view the structures for hydrocarbon deposit.

### **Results and Discussion**

#### **Total Magnetic Intensity Map of the Study Area**

The total magnetic map of the study area is shown in Figure 2 the map can be divided into three main sections these are the low, high and medium magnetic intensities, but minor depressions exist scattered all over the area. The low magnetic intensity value represented by dark green – blue color is found all around most areas in the map but concentrated toward the northeast part ranging between -23.9 - 57.0 nT, the western part of the map is dominated by high magnetic intensity values (pink – red color) with values varying between 82.3-103.3 nT, the two sections are separated by a zone characterized by medium magnetic intensity (62.4 – 76.6 nT) values area depicted by yellow- orange color with concentration toward southwestern part of the map.

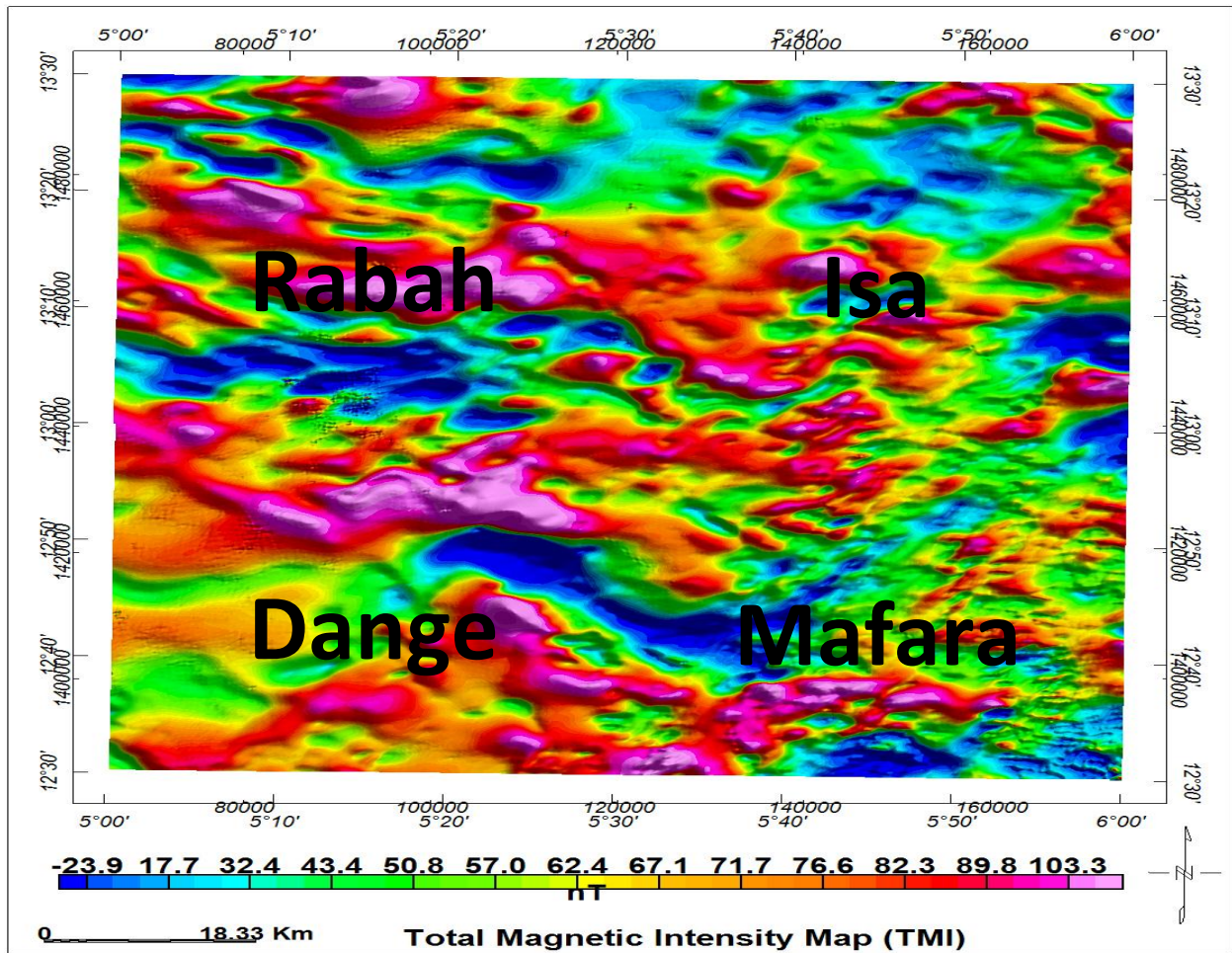


Figure 2 Total magnetic intensity map (TMI) of the study area

### Upward Continuation of Residual Map

The residual map obtained was subjected to upward continuation technique at 5, 10, 15, 20, 25, 30, 35, 40 and 45 km to view the deep seated structures of the area the result is as follows:

### Upward Continuation Map at 5 km

The residual map of the study area was upward continued at 5 km to produce Figure 3. At this height the northeastern part of the map is predominate with dark green – blue color, with blue color observed in the middle toward the southern part. The southwestern part of the map

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is predominated with yellow pink color. The dark – blue color are prevalent in this area, this is the section of the study area having the highest sedimentary thickness.

### **Upward Continuation Map at 10 km**

The map of upward continuation to 10 km is shown in Figure 3. The map shows that there is a net difference between the TMI maps at this flight level. The map can be divided into three sections: at the bottom side of the map is predominantly pink red toward the southwestern part with values ranging from 58.4 to 67.0 nT and the upper part of the map toward northeastern is predominantly low magnetic values of colors green – blue with values ranging from 45.4 to 55.4 nT and the two zones are separated by yellow color of values between 55.5 to 58.3 nT. The pink-red color indicates high magnetic value, green-blue color indicates and yellow color shows medium value

### **Upward Continuation Map at 15 km**

The map of upward continuation to 15km above flight level is shown in Figure 3, at this height basement structures appeared quite distinct from the sedimentary areas of lowest magnetic value found to be at northeast part of the study area (dark green – blue color) and some areas at the central part of the map with magnetic value range between 46.6 to 55.6 nT. The southwestern part of the area is predominated with light pink-red color indicating high magnetic values range between 57.9 to 66.0 nT and yellow color indicating medium magnetic value range between 55.7 to 57.8 nT separate the two magnetic zones around the central area of the map.

### **Upward Continuation Map at 20 km**

The upward continuation map to 20 km Figure 3 shows the area of medium magnetic value (yellow orange colors) dominating the center providing barrier between high values (pink – red) concentrated at the southwestern part and the low magnetic values concentrated at northeastern part of the map. The high values on the map range between 57.8 to 65.6 nT while the low values range between 46.9 to 56.0 nT and medium values are between 56.1 to 57.7 nT.

### **Upward Continuation Map at 25 km**

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The map of upward continuation to 25 km is shown in Figure 3 at this height, a more clear view of the magnetic trends on the map is obtained the low magnetic values ranging between 47.0 to 55.9 nT indicated by green to blue colors is seen to be concentrated at the northeastern part of the map and the high magnetic values (red to pink colors) ranging between 57.7 to 65.3 nT which might be due to igneous rock is the predominate of the southwest part of the area, these magnetic values are separated by a medium (yellow color) of 60.0 to 57.6 values at the center of the map.

#### **Upward Continuation Maps at 30, 35, 40, and 45 km**

The maps of upward continuation to 30, 35 40 and 45 km are shown in Figure 3. At those heights more clear views on the maps were obtained the low magnetic value is seen to be concentrated at the northeastern part of each of the maps and the high magnetic values which might be due to igneous rock is the predominate of the southwest part of the maps, these magnetic values are separated by a medium value at the center of the maps. The magnetic trends of the study area as shown in Figure 4.11 appears to decrease from southwest to the northeastern part of the study area with values 7965.0 to 47.05 nT.

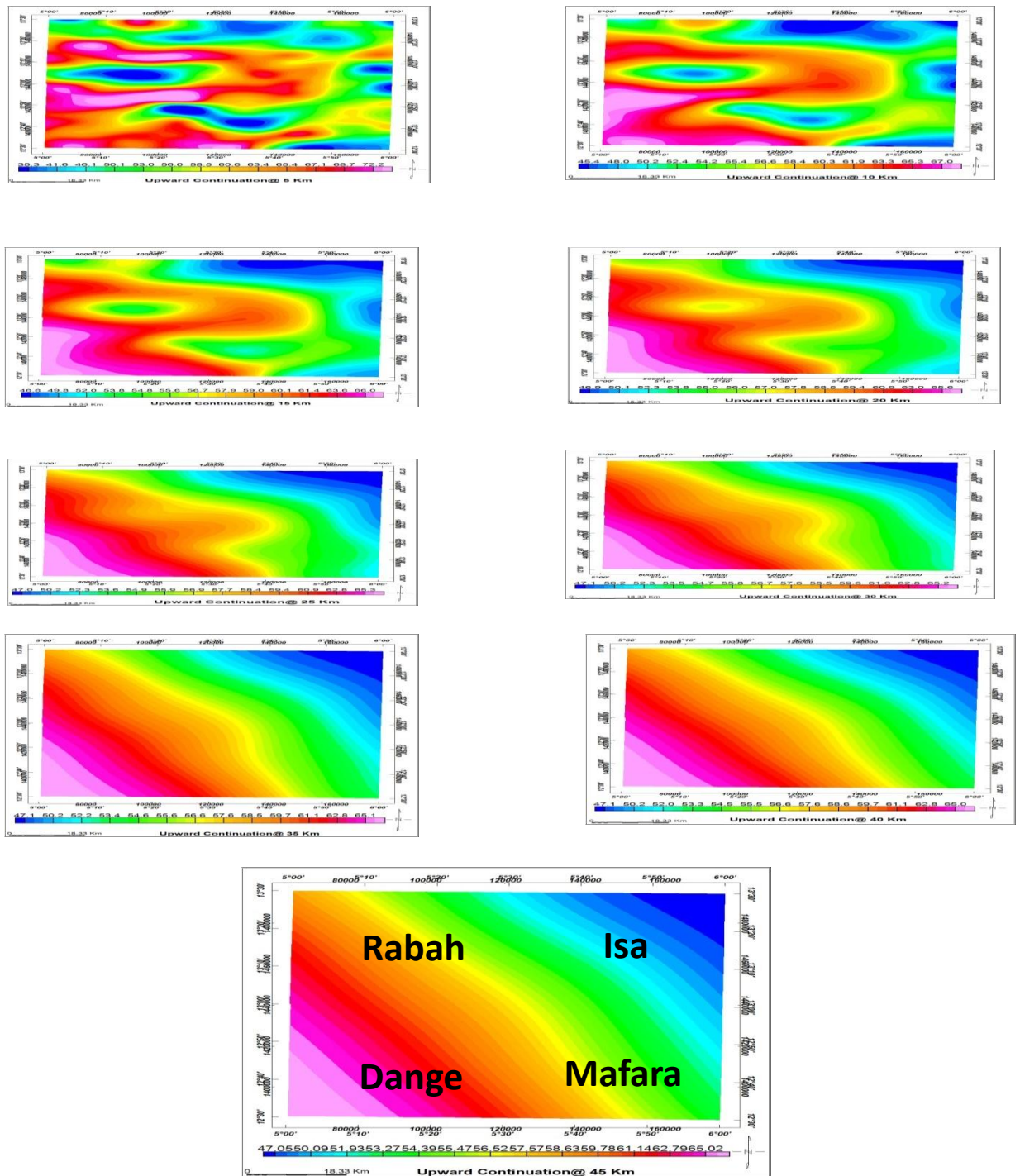


Figure 3 Upward Continuation Maps at Different Height

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## Summary

The total magnetic intensity map of the area revealed that the sedimentary thickness of the northeastern part of Sokoto basin in general, appears to increase from south to north. The result of the Upward continuation on the area carried out at different heights revealed that high sedimentation was seen to be concentrated at the northeastern part around Isa area of each of the maps and the high magnetic values which might be due to igneous rock is the predominant of the southwest part of the maps, these magnetic values are separated by a medium value at the center.

## Conclusion

The trend of the magnetic zone of the study area decreases from SW-NE portions of the map. This result indicates that the portion of low magnetic zones around northeastern part of the study area is the deepest part of the area and is therefore expected to be the potential site for hydrocarbon accumulation.

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