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Estimation of Magnetic Source Depths from Aeromagnetic Data of Maiduguri, Northeastern Nigeria Using Gradient Inversion Method

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Abstract

A quantitative interpretation of the aeromagnetic anomalies of Maiduguri (sheet 90) in the North Eastern region of Nigeria has been carried out using spectral analysis method.

The study area covers approximately 3, 052, 13 sq. kilometre and forms a part of Chad Basin. Regional anomalies were removed from the total magnetic field using 2D least square analysis. The resulting residual data were plotted to obtain 64 profile depth estimations. The depth estimations were obtained from spectral analysis. The estimated depths to magnetic sources were found to vary from 0.175 km to 1.352 km. The results indicate that the sedimentary basin in the area is approximately 1.4 km

This study has revealed that the study area may be targeted for hydrocarbon prospecting based on the magnitude of the sedimentary basin.

Keywords: Aeromagnetic, Spectral, Anomalies, Residual, Sedimentary, Hydrocarbon

1.0 Introduction

Airborne geophysical surveying is the process of measuring the variation of different physical or geochemical parameters of the earth such as distribution of magnetic minerals, density, electric conductivity and radioactive element concentration. The methods used to measure these kinds of parameters are magnetic, gravity, electromagnetic and gamma-ray spectrometry respectively [1].

Aeromagnetic survey is used for mapping the variation of the geomagnetic field, which occurs due to the changes in the percentage of magnetite in the rock. It reflects the variations in the distribution and type of magnetic minerals below the earth surface. Aeromagnetic data allow fast coverage of large and inaccessible areas for subsurface reconnaissance, which makes magnetic data analysis an essential tool of geophysical exploration. Magnetic minerals can be mapped from the surface to greater depth in the rock crust depending on their dimension, shape and the magnetic property of the rock. Sedimentary formations are usually non-magnetic and consequently have little effect whereas igneous and metamorphic rocks exhibit greater variation and become useful in exploring bedrock geology concealed below cover formations.

Variation in magnetic susceptibility combined with other geophysical data and known geology provides important information about the regional geology especially where rock outcrops are scarce or absent [2].

Magnetic anomaly studies in Nigeria have mainly been interpreting large scale subsurface structures with high magnetic susceptibility such as volcanic intrusions. Numerous magnetic anomaly interpretations have used this characteristic for location and depth estimation of these mostly intrusive bodies. Many countries, including Great Britain and Canada, have already been covered by high-sensitivity aeromagnetic surveys. In Nigeria however, a high-resolution aeromagnetic survey covering the whole country has not been conducted yet. The aeromagnetic survey analyzed in this report is one of the largest existing within Nigeria [3].

The separation of anomalies of regional and local origin is an important step in the interpretation of a potential field data [4] and even in the field it may be necessary to estimate background so that the significance of local anomalies can be assessed [5]. These methods for regional-residual separation have been successfully incorporated into the processing and interpretation of magnetic data. They, however have their limitations.

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The focus of this study is to isolate the magnetic anomalies of geologic interest from aeromagnetic data using computer processing, and interpretation of these anomalies for rock types and possible mineral concentration. And more importantly, estimating magnetic depth to basement of the Area so as to be able to elucidate the topography of the basement rock giving rise to the observed magnetic anomalies.

2.0 Description of the Study Area and Geological Settings

The Chad basin is an intra-continental rifted basin, which extends from Northeastern Nigeria to Chad Republic, Niger Republic and the Cameroon within latitudes 10°N to 14°N and longitudes 12°E to 15°E (Figure 1).

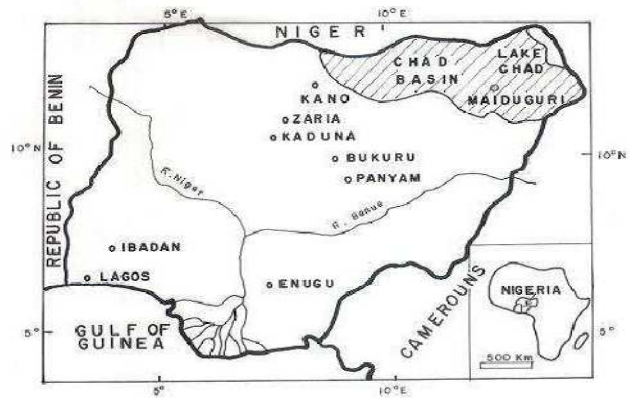

Figure 1: Map of Nigeria showing the location of Chad (Bornu) Basin, inset is a map of Africa showing the location (source: [6])

It is believed to be genetically related to the Benue Trough, which resulted from a failed arm of a triple junction when South American continent separated from the African continent in Early Cretaceous. These two basins are however, separated by the Zambuk Ridge [7,8]. Since the late 70s, the Nigerian sector of the basin has been an area of interest in terms of hydrocarbon exploration mainly by the Nigerian National Petroleum Corporation (NNPC). Early exploration works were by Shell-D Arcy in 1938; and later Mobil Exploration Nigeria Limited in 1955. About 60 percent of the basin is in a grid zone on the southern edge of the Sahara desert and does not contribute to the surface flow towards the Lake Chad.

The Chad basin is one of several basins within the West and Central African rift system and is generally related to the Benue trough [7]. It consists of several sub-basins spread around the republics of Niger, Chad, Cameroon and Nigeria [8]. The Nigerian section are delineated into three sub-basins which are prolific for hydrocarbons accumulation [9]. These are centered around Gubio to the SW, Maiduguri to the South and Lake Chad to the North (Figure 1). The Chad Basing, which is located on Lake Chad, is the largest inland basin in Africa occupying an area of approximately 2,500,000 km^2 extending over parts of the republic of Niger, Chad, Sudan and the northern portions of Cameroon and Nigeria [10]. The altitude of the basin ranges from 300 m within the lake to about 530 m at the western margin, along a distance of about 240 km. The Basin has developed at the intersection of many rifts, mainly in an extension of the Benue Trough. Major grabens then developed and sedimentation started [11].

3.0 Methodology, Data Acquisition and Analysis

3.1 Data Source

Airborne magnetometer survey map (sheet 90) of contours to total magnetic field intensity (TMI) published by the Nigeria Geological Survey Agency (NGSA), airborne geophysical series on a scale of 1:100,000 were used as basic data for determining the nature of magnetic anomalies over the area. The contours interval is variable at 2.5,5, 10 and 50 nT. The survey was carried out along a series of North-South lines with a spacing of 2 km and an average elevation of 152m above the ground level.

The map was carefully digitized using semi-automated method. Although hand digitization is the most elementary and least efficient method of digitization, but an introduction of AutoCAD software in gridding the map made the digitization easier. The spacing interval of 0.875km imposes a Nyquist frequency of 0.57km^{-1}.

3.2 Regional - Residual Separation

After the deduction of total magnetic field data from the aeromagnetic map, Regional field were subtracted from Total Magnetic Field to give Residual Anomaly and this was implemented using a least square polynomial fit for potential field data analysis and short programmed was written in Matlab [4]; i.e.

$$g(x,y)=a_1+a_2x+a_3y+a_4x^2+a_5xy+a_6y^2+\ldots \quad (1)$$

The general form of equation (1) is a polynomial of degree n, which gives

$$g(x,y) = \sum_{j=1}^{n} aj\, pj(xi,yi) \quad (2)$$

Where a_1, a_2… a_n, are coefficient to be determined by adjustment using least square method and P_1… P_2 are chosen function of x and y called the basic function [4].

Solving the series of simultaneous equation or matrix will give coefficients of a_1 a_2, and a_3 of the best fitting linear trend surface by the least squares criterion [4], which represents the regional trend.

$$g(x,y) = a_1 + a_2x + a_3y. \quad (3)$$

3.3 Result of Regional-Residual Separation

Coefficients a_1, a_2 and a_3 were deduced from digitized magnetic intensity values using least square methods through a Matlab code and a linear trend equation of this form was obtained.

$$g(x,y) = 773.09 – (0.5898)X + (1.3326)Y \quad (4)$$

where X and Y are grid co-ordinates which describe the position of the data points with respect to the origin taken axes of the data array. The regional values were then subtracted directly from the observed aeromagnetic data to obtain the residual anomalies i.e. $R(x,y) = T(x,y) - g(x,y)$

$$= T(x,y) – 773.09 – (0.5898)X + (1.3326)Y \quad (5)$$

where T = observed magnetic data total magnetic intensity.

Figure 2, Figure 3 and Figure 4 show, respectively, re-contoured, contoured residual and regional anomaly map obtained from the implementation of the least squares plane surface polynomial fit.

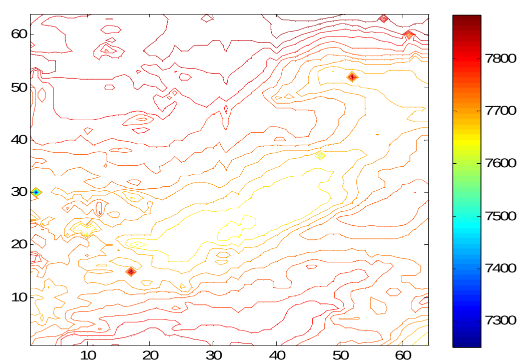

Figure 2: Re-contoured total aeromagnetic intensity field map of Maiduguri

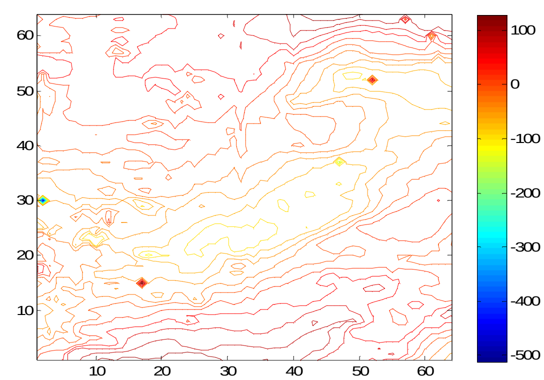

Figure 3: Contoured residual anomaly map of Maiduguri

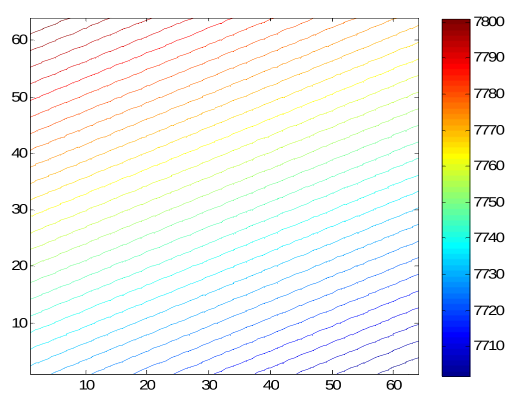

Figure 4: Regional anomaly map of Maiduguri.

3.4 Qualitative Interpretation of the Residual Map

The Residual magnetic map (Figure 3), is relatively complex, with predominance of normal magnetization i.e. a high magnetic value occurring in the North and Southern region of the map, relatively low magnetic value noticeable in the North-East, through the central, down to the South-Western region of the map; while a bit lower magnetic value is spotted at the Western part of the map. The magnetic contours of the residual map are relatively smooth and the variations are small, reflecting the basement rocks rather than the near-surface features [12]. Deep features are frequently camouflaged by higher frequency magnetic effects originating nearer to the surface [12] as noticed in some points towards the North-East and South-Western part of the map.

It was observed that the magnetic sources are shallower at the North-East as well as the Southern region of the map. This is arrived at from the fact that, the closer the contours, i.e., the greater the gradients, the shallower, in general, is the source. Also a major basement fault is suspected at the central region of the map as a result of a well-defined boundary between the contours with appreciably different relief [13]. Finally, the prominent elliptical closures and nosing of contours as identified on the residual anomaly map represent geological lineaments [14]. The main trend of the lineaments is NE-SW with a subordinate E-W trend.

3.5 Estimates of the Magnetic Basement Depths

A MatLab program was written to compute the 1‒D Fourier Amplitude Spectrum of the Residual Anomaly map which was taken across the profile (South ‒North) of Maiduguri (sheet 90). The program was also modified to incorporate *''Low Hanning pass filter''* which was used in Smoothing Aeromagnetic Data.

The Smoothed Aeromagnetic Data was then Fast Fourier transform(fft) using 1‒D, Each profile generated from the Regional-Residual Separation was then divided into segment, such that each Segment consists of fourteen (14) data points with overlapping of four data point [i.e. 1-14 (1^{st} segment), 11-24 (2^{nd} Segment),...]

The depths to magnetic Source were obtained using the equations below:

$$h_1 = -\frac{m(1)}{4\pi} \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

$$h_2 = -\frac{m(2)}{4\pi} \ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

These two sources, h_1 and h_2, account for the first depth deriving from spectral evaluation. The first is magnetic sources on the surface of the basement complex bounding the North Central block. The second and more important sources are the magnetic rocks that intrude on the basement surface. Intra-basement features like fractures and faults are other sources of the second depth.

The Slope M, of the straight line segment for each profile was determined and the depths for deeper and shallow sources were calculated. This is one of the important aspect of magnetic interpretation, the results of depth estimates supply information about the thickness of the younger granite basement complex, and it is therefore possible to delineate the configuration of the basement complex at low cost and high accuracy [15]

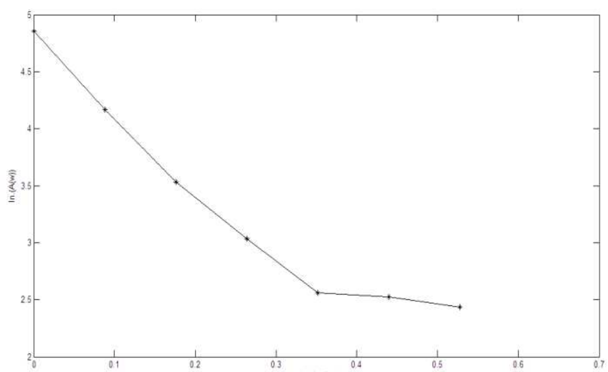

Figure 5: Spectral analysis graph from Profile 10

3.6 Discussion and Conclusion

The Residual aeromagnetic anomaly divides the study area into regions of positive (high), intermediate and negative (low) magnetic anomalies as shown in figure 3. This shows that magnetic data usually display positive-negative anomalies which are due to the dipolar nature of the magnetic sources and their interaction with the Earth's field [16]. It can be observed that in the North central region down to the south-west and some other part of the map, there is an occurrence of hyperbyssal intrusions (Dikes) which are sheet-like in shape. They cross-cut the older granite rocks at about hundreds of meters at the time of intrusion, which is an existence of a fault or fracture in the zone. Likewise laterally spread intrusion (sills) can also be found in the North West and some other part of the map, this shows that the bedding plane zone offer a weaker resistance to the intruding magma that is, there is no fault system in the roof zones. The negative anomalies occurred at the southern region and up north of the basement complex of the study Area, this implies that some of the prominent negative anomalies may not be accompanied by any surface expression of ring complex.

This raises the interesting possibility that beneath these anomalies lie unexposed younger granite intrusions buried at relatively shallow depth; such unexposed structures are potentially of economic interest. The Intermediate anomalies form the most extensive anomalies, which were found to be lying almost all over the undifferentiated basement complex and older granites, then extends to a less extent to the younger Granites. The positive magnetic anomalies appear to be lying over parts of the older granites, and it can be observed to be found in the North-East region, which then extends downward from the central part to the south-west region of the undifferentiated basement complex. The rock types associated with positive magnetic anomaly values are usually made up of basic intrusive or rocks rich in ferromagnesian minerals e.g. gabbros, norites, anorthosites, trocolites, dolerites the main minerals in basic rocks are calcic plagioclase, pyroxenes (augite and hypersthenes), olivine e.t.c. It can also be observed that basic rocks are under saturated and therefore do not usually contain free silica (quartz). This is because both remanent and induced magnetism can contribute to the magnetic field produced by basic rocks, and for every old basic intrusive, the remanent magnetization can be a dominant factor contributing to magnetic anomalies. More so basic rocks generally have high iron content and are more magnetic than others, so magnetic methods can be used to map them efficiently.

The Results of the Depth Estimate is as follows

1. The results show that the thickness of the sedimentary rock varies from 0.00079km (0.79m) to 1.35227km (1,353.3m).
2. The depths estimated along the profiles, revealed the depths at specific regions of anomalies. This indicates that the North-Eastern part of the map is averagely deeper than the Southern part of the map.
3. The shallow depths obtained ranges from 0.00079km to 0.46136km this is probably due to exposed magnetic rocks. The deeper depths of the magnetic sources vary from 0.175 to 1.35227km.
4. The depths correlation of gradient inversion method and earlier depths estimated using 1D- Spectral analysis found to be in good agreement.

It can be inferred from the earlier discussion that interpretation of aeromagnetic data has some significant features:

1. Depth estimates from spectral analysis of magnetic data indicate a two depth source model. The depth of the deeper source range from 175m to 1,352m, this could be identified with basement. The shallow source range from 0.79m to 461.64m, this could be attributed to near surface intrusive and low-laying river valleys. The deeper depths Estimate are in agreement with those from gravity data over the upper Benue trough by [8].
2. Recently, exploration works for hydrocarbon began in the Chad Basin. In the present study area, hydrocarbon prospects are largely doubtful because of the presence of basalt in the area whose emplacement may have destroyed geological traps.
3. Also, the high temperature that accompanied their emplacement may have converted any existing liquid hydrocarbon to gas. This could be lost by escape through fractures in the area [14].
4. Finally, depth estimates in the area is generally low to favour hydrocarbon formation except in the NE section.

The results obtained indicate two depth source areas. On the average the deeper sources range from 175m to about 1,352m while the shallower sources range from 0.78m to about 461m. The interpretation of the aeromagnetic maps of part of Chad Basin area revealed that the Sedimentary cover is generally low and therefore is not likely to favour hydrocarbon formation.
The results of this study are within the range of depths predicted by some earlier workers. Since a maximum depth of 1,353m was obtained, the area may be a target for oil and mineral exploration. This correlates with the work of [6].

4.0 Recommendation

The nature of the residual anomaly and the rocks and minerals associated with the magnetic susceptibilities suggests that further geophysical prospecting should be carried out in the area. Though, exploration for hydrocarbon works were recently carried out in the Chad Basin, Nigeria, in the study area, hydrocarbon prospects are largely doubtful because of the low values of the residual magnetic anomalies. However other valuable rocks/minerals may be sought for, but this could only be confirmed if a quantitative interpretation is carried out over this region. Furthermore, the relationship between the anomalies and mineralization in the study area should be looked into. A detailed geophysical study of elucidated areas with high basement depths is also recommended to be carried out on the study area.

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