Analysis of Aeromagnetic Data across Kebbi State, Nigeria

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Abstract: The study lies in the lower Basin of Lullemmeden and extends from longitudes 3°30”- 6°58” and latitudes 10°20”-14°00”. The objectives of the study were to extract the magnetic anomalies of geologic interest from the residual magnetic data and to determine the depth to magnetic sources giving rise to magnetic anomalies using spectral analysis. To achieve these, twelve aeromagnetic maps (sheets 26, 27, 28, 48, 49, 50, 71, 72, 73, 94, 95, and 96) were used and digitized. SPT 98 software was used to obtain the spectral plots from which the depths were determined using $D = -M/2$. The results revealed clearly two magnetic depth layers. The depth to the shallow magnetic layer $D_1$ varies from 0.22 km to 0.95 km with an average depth of 0.67 km while the deeper magnetic layer $D_2$ varies from 0.80 km to 1.72 km with an average depth of 1.25 km. These values obtained are too small to allow any accumulation of hydrocarbon in the study area. Other geophysical techniques such as seismic and resistivity should be used in the area.

Keywords: aeromagnetic data; regional-residual separation; spectral analysis; magnetic layers.
1. Introduction

An aeromagnetic survey is a common type of geophysical survey carried out using a magnetometer board or towed behind an aircraft. The principle is similar to a magnetic survey carried out with a hand-held magnetometer, but allows much larger areas of the earth’s surface to be covered quickly for regional reconnaissance. The aircraft typically flies in a grid like pattern with height and line spacing determining the resolution of the data (and cost of the survey per unit area) (Olasehinde, 2009).

Aeromagnetic surveys are widely used to aid in the production of geological maps and are also commonly used during mineral exploration. Some minerals deposits are associated with an increase in the abundance of magnetic minerals, and occasionally the target may itself be magnetic (e.g. iron ore deposits), but often the elucidation of surface structure of the upper crust is the most valuable contribution of the aeromagnetic data (Hamza and Garba, 2010).

Some of the roles of aeromagnetic survey as outlined by Sharma (1987) as well as Hamza and Garba (2010) are as follows: (a) in prospecting for oil, aeromagnetic data can give information from which one can determine depths to basement rocks and thus locate and define the extent of sedimentary basins, (b) recognition and interpretation of faulting, shearing and fracturing not only as potential hosts for a variety of minerals but also an indirect guide to epigenetic, stress related mineralization in the surrounding rocks, and (c) direct detection of deposits of certain iron ores.

The aim of this study is to process the total magnetic field intensity data across Kebbi State with the following objectives: (1) to obtain the residual magnetic data, (2) to extract the magnetic anomalies of geologic interest from the residual magnetic data obtained above, and (3) to determine the depth to magnetic sources giving rise to magnetic anomalies using spectral analysis.

2. Location and Geology of the Study Area

The study area is Kebbi State in Sokoto Basin in North-Western Nigeria (Fig. 1), which forms the south-eastern sector of the Lullemmeden Basin, one of the young (Mesozoic–Tertiary) inland cratanoic sedimentary basins of West Africa. Sokoto Basin lies between longitudes 3°30” - 6°58” and latitudes 10°20” - 14°00” with an estimated area of 59,570 km². The Basin is covered by thirty two sheets of aeromagnetic maps. Though the study area (Kebbi) is covered by about sixteen sheets of aeromagnetic maps, out of which twelve was used for the present study. Fig. 1 is the geological map of Nigeria.

The Sokoto Basin of northwestern Nigeria consists predominantly of a gentle undulating plain, underlain by metamorphic rocks (Sheu et al., 2004).
3. Material and Methodology

The selected aeromagnetic map sheets 26, 27, 28, 48, 49, 50, 71, 72, 73, 94, 95 and 96 were used for this research. These are published maps by the Nigerian Geological Survey Agency (NGSA), then Geological Survey of Nigeria, which produced the aeromagnetic map of substantial part of Nigeria between 1974 and 1980. The data were collected at a nominal flight altitude of 152.4 m along N-S flight lines spaced approximately 2 km apart. The maps are on scale of 1:100,000 and half-degree sheets. A correction based on the International Geomagnetic Reference Field (IGRF) of 1974 was applied to all the data.

3.1. Digitization, Contouring and Regional – Residual Separation

The present study adopted the grid layout (visual interpolation) method in digitizing the twelve aeromagnetic maps used in the study area. This method has been applied in several aeromagnetic studies and very good results have been achieved (Ajakaiye et al., 1985 and 1991; Ojo, 1990; Udensi, 2001; Sheu et al., 2004; Adetona et al., 2007).

The maps were digitized on a 1.5 × 1.5 km grid system. This spacing imposes a Nyquist frequency of 1/3 km\(^{-1}\). Thus, the narrowest magnetic feature that can be defined by the digitized data has a width of 3 km. Previous studies with crustal aeromagnetic anomalies (Hall, 1968 and 1974; Udensi,
2001) show that this spacing is suitable for the representation of the continuous data in a discrete form without losing details and equally suitable for interpretation of magnetic anomalies resulting from regional crustal structures, which are larger than 6 km and thus lies below the frequency range for which computational error arising from aliasing do not occur.

Having digitized the map, the data were stored in a computer storage device and subsequently fed into a computer program (SURFER 8). This program was written to pick all the data points row by row, calculate the longitude and latitude using base values already supplied. The output is in the form of columns of x, y, z where x, y and z represent longitude, latitude and magnetic value respectively. The results obtained were fed into a contouring package called “SURFER”. The total magnetic field map over study area was produced using this package. This is shown in Fig. 2.

![Figure 2. Total magnetic field intensity map across Kebbi State, Nigeria.](image)

SURFER 8 was also used to derive the residual magnetic values by subtracting values of the regional fields from the total magnetic values at the grid cross point (Fig. 3).

The values obtained for the regional field was subtracted from the total magnetic field values to give the residual magnetic values at the grid cross point. The composite contour map of the calculated residual values is shown in Fig. 4.

The residual map is therefore used for spectral analysis.
3.2. Spectral Analysis

In order to spectrally determine depth to layer of magnetization, the study area was divided into twenty five overlapping sections. The locations of the sections are indicated in Table 1. Each section covers depth to the assemblage of anomalous bodies (Spector and Grant, 1970; Hahn et al., 1976). A
computer programme SPT 98 was used to evaluate radial spectrum for each section. Graph of the logarithm of the spectral energies against their corresponding frequencies for each blocks are shown in Fig. 5. The first view points were generated from the deepest layers whose locations most likely in error were ignored, since it has been established that error in depth estimation increases with depth of source (Pal et al., 1978). The gradients of the linear segments were evaluated and $D = -m/2$ was used to calculate the depth to the causative bodies (Spector and Grant, 1970). Where $D$ is the mean depth of the burial of ensemble and $m$ is the slope of best fit. From the earth surface downward, these depths are shown as $D_1$ and $D_2$ in Table 1.

4. Results

4.1. Residual Map

(i) Many of the anomalies in the residual magnetic map of Fig. 4 have short wavelength and are more or less circular in the underlying basement surface. There are high magnetic values around NE and WS of the study area. These suggest regions where the basements are shallow.

(ii) Series of magnetic closures are observed at the central, trending NE which lies approximately at Lat. $12.2^\circ$N at the central area, and few at SE which lies approximately between latitude $11.8^\circ$N and longitude $4.6^\circ$E. The nature of these closures is indications of the depth to burial by the basin.

(iii) Fairly discontinuities and lineament exists in the study area in a NE-SW and NW-SE trending patterns. This is an indication of possible faults zones within the basement complex of the basin.

4.2. Spectral Depth

It is important to note that spectral depth are in general average depth and individual depth estimated may have values which differ from one another. The primary sources that account for the first layer depth derived from the statistical spectral analysis are the magnetic rocks that intrude the sedimentary formation. An estimated depth ranging from 0.22 km to 0.95 km was observed with an average of 0.67 km. With maximum around $12 – 13^\circ$ latitude and $3.5 – 4.5^\circ$ longitude (covering Birnin Kebbi, Bunza, Kalgo area) and minimum value observed around latitude $11 – 12^\circ$ and longitude $3.5 – 4.5^\circ$ (covering Kamba, Mahuta area).

The second layer depth may be attributed to magnetic rocks that are emplaced or intruded into the basement underlying the sedimentary basin. Also, intra-basement features such as fractures could equally contribute to sources that accounted for the second layer depth. The second layer depth thus invariably represents a depth to the underlying magnetic basement rock within the study area. For this, an estimated depth ranging from 0.80 km to 1.72 km was observed with an average of 1.25 km. This
also represents the average thickness of the sedimentary pile within the study area.

Table 1. Estimated depth to the Deep (D₂) and Shallow (D₁) magnetic sources in km

<table>
<thead>
<tr>
<th>Section</th>
<th>Long (degree)</th>
<th>Lat (degree)</th>
<th>D₁ (km)</th>
<th>D₂ (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.5 – 4.5</td>
<td>12 – 13</td>
<td>0.95</td>
<td>1.50</td>
</tr>
<tr>
<td>2</td>
<td>4.0 – 5.0</td>
<td>12 – 13</td>
<td>0.36</td>
<td>1.25</td>
</tr>
<tr>
<td>3</td>
<td>3.5 – 4.5</td>
<td>12 – 11</td>
<td>0.22</td>
<td>0.80</td>
</tr>
<tr>
<td>4</td>
<td>4.0 – 5.0</td>
<td>12 – 11</td>
<td>0.37</td>
<td>1.00</td>
</tr>
<tr>
<td>5</td>
<td>3.5 – 4.0</td>
<td>11.5 – 13</td>
<td>0.36</td>
<td>1.65</td>
</tr>
<tr>
<td>6</td>
<td>4.0 – 4.5</td>
<td>11.5 – 13</td>
<td>0.50</td>
<td>1.00</td>
</tr>
<tr>
<td>7</td>
<td>4.5 – 5.0</td>
<td>11.5 – 13</td>
<td>0.63</td>
<td>1.13</td>
</tr>
<tr>
<td>8</td>
<td>3.5 – 5.0</td>
<td>11 – 11.5</td>
<td>0.63</td>
<td>1.00</td>
</tr>
<tr>
<td>9</td>
<td>3.5 – 5.0</td>
<td>11.5 – 12</td>
<td>0.83</td>
<td>1.00</td>
</tr>
<tr>
<td>10</td>
<td>3.5 – 5.0</td>
<td>12 – 12.5</td>
<td>0.83</td>
<td>1.25</td>
</tr>
<tr>
<td>11</td>
<td>3.5 – 5.0</td>
<td>12.5 – 13</td>
<td>0.82</td>
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<td>11 – 11.5</td>
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<td>4.0 – 5.0</td>
<td>11 – 11.5</td>
<td>0.73</td>
<td>1.25</td>
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<tr>
<td>14</td>
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<td>11 – 12</td>
<td>0.60</td>
<td>1.13</td>
</tr>
<tr>
<td>15</td>
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<td>11 – 12</td>
<td>0.91</td>
<td>1.11</td>
</tr>
<tr>
<td>16</td>
<td>4.5 – 5.0</td>
<td>11 – 12</td>
<td>0.94</td>
<td>1.33</td>
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<tr>
<td>17</td>
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<td>11.5 – 12.5</td>
<td>0.72</td>
<td>1.25</td>
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<tr>
<td>18</td>
<td>4.0 – 4.5</td>
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<td>0.75</td>
<td>1.72</td>
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<tr>
<td>19</td>
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<td>0.76</td>
<td>1.60</td>
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<tr>
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<td>12 – 13</td>
<td>0.65</td>
<td>1.52</td>
</tr>
<tr>
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<td>12 – 13</td>
<td>0.56</td>
<td>1.43</td>
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<tr>
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<td>12 – 13</td>
<td>0.83</td>
<td>1.00</td>
</tr>
<tr>
<td>23</td>
<td>4.0 – 5.0</td>
<td>12.5 – 13</td>
<td>0.50</td>
<td>1.13</td>
</tr>
<tr>
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<td>3.5 – 4.0</td>
<td>11 – 13</td>
<td>0.92</td>
<td>1.67</td>
</tr>
<tr>
<td>25</td>
<td>4.0 – 4.5</td>
<td>11 – 13</td>
<td>0.70</td>
<td>1.25</td>
</tr>
</tbody>
</table>

**Average** 0.67 1.25
Umego (1990) stated from preliminary interpretation of gravity measurement within the basin that the maximum possible thickness of the sedimentary section in Sokoto basin (in which study area belong) is no where considered exceeding 2 km. This average depth of 1.25 km is well in agreement with the work of previous workers that had used several methods to estimate the thickness of the basin.

**Figure 5.** Graph of the logarithm of the spectral energies against their corresponding frequencies for each blocks.
Umego (1990) used Wermer deconvolution method and got sediment thickness range of 1.2 km to 1.8 km. The result of this study also correlates with the result of Sheu & Udensi (2004) where an estimated average value of 1.386 km was obtained in upper area of the Basin. Also the result is also in line with Adetona et al. (2007) where an estimated average value of 1.45 km was obtained.

5. Conclusions and Recommendations

A maximum of 1.72 km obtained in this study is less than 2.3 km minimum depth recommended by Wright et al. (1985) with threshold temperature of 115 °C for the accumulation of oil from organic deposit. Nigeria is a country blessed with human and natural resources. Though based on previous and present researches, the Basin is known to be very shallow and therefore ruled out any hydrocarbons potentials. However, the study area can also have some hydrocarbon potentials if other modern methods are implored.

Based on the result obtained from the study, the following recommendations are made: (i) The use of other geophysical technique such as seismic, resistivity, and well logging in drilled boreholes should be encourage in the area. (ii) A new series of maps recently published by Nigerian Geological Survey Agency should be compared with the old ones in view to see if there will be difference in the results since the maps used for the present study was carried out more than thirty years ago. (iii) A detailed spectral depth determination with reasonable number of windows should be carried out in the study area. This can give a general picture of sedimentary thickness in the basin.

References


