Depth to Basement Determination Using Source Parameter Imaging (SPI) of Aeromagnetic Data: An Application to Lower Sokoto Basin, Northwest, Nigeria

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Abstract: Source Parameter Imaging (SPI) of aeromagnetic data covering latitude 10.50° – 11.50° N and longitude 4° – 5° E which corresponds to some part of lower Sokoto basin, northwest, Nigeria, was carried out for the purpose of interpreting the aeromagnetic data over Kaoje, Shanga, Konkoso and Yelwa area northwest Nigeria. The study area is covered by 4 aeromagnetic maps. The result of the Source Parameter Imaging (SPI) has its highest sedimentary thickness of about 2.8 to 3 km which could be found around at central parts of Konkoso, Kaoje and at Northern parts of Kaoje could be sufficient for hydrocarbon prospecting. The shallow sedimentary thickness could also be found predominantly at Shanga, Yelwa and Northern part at Konkoso and Kaoje at west eastern part. These areas were suggested as having the highest sedimentary thickness of about 2.8 to 3 km, as this may determine the presence of hydrocarbon.

Keywords: Aeromagnetic data, Source Parameter Imaging and Sedimentary thickness

1. Introduction

The search for mineral deposits and hydrocarbon (oil and gas) has been a major business challenge in Nigeria since the pre-colonial era and the 1960s respectively. The bedrock of Nigeria’s economy has been the solid mineral and currently the lucrative oil sector due to its high profitability.
Over 80 percent of the country’s revenue comes from export and domestic sales of the oil and gas upon which approximately over 170 million growing population depends on. As the hydrocarbon potential of the prolific Niger delta becomes depleted or in the near future may be exhausted due to continuous exploitation, attention needs to be shifted to other sedimentary basins. The sokoto basin and lower sokoto basin in particular is one of those basins being suspected to have high hydrocarbon potential, besides economic mineral deposits concentration. Recently, the petroleum potential of the trough has been of great interest to geologists and geophysicists. The Nigerian government through the Nigerian National Petroleum Corporation (NNPC) and many oil companies will invested heavily in this part of the basin if oil and gas is confirmed. However, once hydrocarbon is confirmed in the area efforts and more money will be sunk into the area with the hope of finding oil in the near feature.

The Source Parameter Imaging (SPI) of aeromagnetic fields over the area would differentiate and characterise regions of sedimentary thickening from those of uplifted or shallow basement and also to determine the depths to the magnetic sources. The results could be used to suggest whether or not the study area has the potential for oil/gas and mineral deposits concentration. This study area is bounded by latitudes 10.50’N to 11.50’N and longitudes 4.0’E to 5.0’E located within some part of lower Sokoto Basin, Northwest Nigeria and was covered by 4 aeromagnetic maps.

![Geology of the study area](image)

**Fig. 1:** Geology of the study area after Nigeria geological survey agency (NGSA 2005)

### 2. Materials and Method

The aeromagnetic dataset used for this study was obtained from the Nigerian Geological Survey Agency as a part of the nation-wide aeromagnetic survey between 1974 and 1980. The
magnetic data were collected at a nominal flight altitude of 154.2 m along approximately N-S flight lines (nearly perpendicular to predicted geological strikes in the area), spaced 2 km apart. The component of the field measured was the total magnetic field. The study area is covered by four (4) aeromagnetic maps of total-field intensity in $1/2^\circ$ by $1/2^\circ$ sheets. These are numbers 95, 96, 117, and 118 on a scale of 1:100,000. The magnetic values were plotted at 10nT (nano Tesla) interval. The actual magnetic values were reduced by 25,000 gammas before plotting the contour maps (Huntings, 1976). This means that the value of 25,000 gammas should 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 sheets number. The unified composite dataset for the study area was produced after removing the edge effect. Oasis montaj was used to import the dataset. The dataset consists of three columns (longitude, latitude and magnetic values). The composite map was produced using Oasis Montaj. Version 7.2.

The Source Parameter Imaging (SPI) function is a quick, easy, and powerful method for calculating the depth of magnetic sources. Its accuracy has been shown to be +/- 20% in tests on real data sets with drill whole control. This accuracy is similar to that of Euler deconvolution, however SPI has the advantage of producing a more complete set of coherent solution points and it is easier to use. A stated goal of the SPI method (Thurston and Smith, 1997) is that the resulting images can be easily interpreted by someone who is an expert in the local geology. The SPI method (Thurston and Smith, 1997) estimates the depth from the local wave number of the analytical signal. The analytical signal $A_1(x,z)$ is defined by Nabighian (1972) as:

$$A_1(x,z) = \frac{\partial M(x,z)}{\partial x} - j \frac{\partial M(x,z)}{\partial z}$$

(1)

where $(X,Z)$ is the magnitude of the anomalous total magnetic field, $j$ is the imaginary number; $z$ and $x$ are Cartesian coordinates for the vertical direction and the horizontal direction respectively. From the work of Nabighian (1972), he shows that the horizontal and vertical derivatives comprising the real and imaginary parts of the 2D analytical signal are related as follows:

$$\frac{\partial M(x,z)}{\partial x} \leftrightarrow - \frac{\partial M(x,z)}{\partial z}$$

(2)
where \( \Leftrightarrow \) denotes a Hilbert transformation pair. The local wave number \( k_1 \) is defined by Thurston and Smith (1997) to be

\[
k_1 = \frac{\partial}{\partial x} \tan^{-1} \left[ \frac{\partial^2 M}{\partial^2 z} \left/ \frac{\partial^2 M}{\partial x \partial z} \right. \right]
\]

(3)

The concept of an analytic signal comprising second-order derivatives of the total field, if used in a manner similar to that used by Hsu et al. (1996), the Hilbert transform and the vertical-derivative operators are linear, so the vertical derivative of (2) will give the Hilbert transform pair,

\[
\frac{\partial^2 M(x, z)}{\partial x \partial z} \Leftrightarrow -\frac{\partial^2 M(x, z)}{\partial^2 z}
\]

(4)

Thus the analytic signal could be defined based on second-order derivatives, \( A_2(x, z) \),

\[
A_2(x, z) = \frac{\partial^2 M(x, z)}{\partial x \partial z} - j \frac{\partial^2 M(x, z)}{\partial^2 z}
\]

(5)

This gives rise to a second-order local wave number \( k_2 \), where

\[
k_2 = \frac{\partial}{\partial x} \tan^{-1} \left[ \frac{\partial^2 M}{\partial^2 z} \left/ \frac{\partial^2 M}{\partial x \partial z} \right. \right]
\]

(6)

The first- and second-order local wave numbers are used to determine the most appropriate model and a depth estimate independent of any assumptions about a model. Nabighian (1972) gives the expression for the vertical and horizontal gradient of a sloping contact model as:

\[
\frac{\partial M}{\partial z} = 2KFC \sin d \frac{h_c \cos(2l - d - 90) + x \sin(2l - d - 90)}{h_c^2 + x^2}
\]

(7)

\[
\frac{\partial M}{\partial z} = 2KFC \sin d \frac{x \cos(2l - d - 90) + h_c \sin(2l - d - 90)}{h_c^2 + x^2}
\]

(8)

where \( K \) is the susceptibility contrast at the contact, \( F \) is the magnitude of the earth’s magnetic field (the inducing field), \( c = 1 - \cos^2 i \sin^2 \alpha, \alpha \) is the angle between the positive x-axis and magnetic north, \( i \) is the ambient-field inclination, \( \tan I = \sin i / \cos 8 \), \( d \) is the dip (measured from the positive x-axis), \( h_c \) is the depth to the top of the contact and all trigonometric arguments are in degrees. The coordinate system has been defined such that the origin of the profile line \( (x = 0) \) is directly over the edge.

The expression for the magnetic-field anomaly due to a dipping thin sheet is
Reford (1964), where w is the thickness and \(h_1\) the depth to the top of the thin sheet. The expression for the magnetic-field anomaly due to a long horizontal cylinder is

\[
M(x, z) = 2KF_{cw} \frac{h_t \sin(2I - d) - x \cos(2I - d)}{h_t^2 + x^2}
\]  

(9)

Murthy, K. S. R., & Mishra, D. C. (1980), where \(S\) is the cross-sectional area and \(h_1\) is the depth to the Centre of the horizontal cylinder. Substituting (7), (8), (9) and (10) into the expression for the first- and second-order (i.e. (3) and (6) respectively) local wave numbers, we obtain, after some amplification, a remarkable result as:

\[
k_i = \frac{(n_k + 1)h_k}{h_k^2 + x^2}
\]  

(11)

\[
k_2 = \frac{(n_k + 2)h_k}{h_k^2 + x^2}
\]  

(12)

where \(n_k\) is the SPI structural index (subscript \(k = c, t\) or \(h\)), and \(n_c = 0\), \(n_t = 1\) and \(n_h = 2\) for the contact, thin sheet and horizontal cylinder models, respectively. From (11) and (12) above, it is evident that the first- and second-order local wave numbers are independent of the Susceptibility contrast, the dip of the source and the inclination, declination, and the strength of the earth’s magnetic field.

The contact, thin sheet and horizontal cylinder are all two-dimensional models (infinite strike extent), so it is an implicit assumption of the SPI method that the geology is two dimensional. If the body is two-dimensional and there is no interference from nearby bodies, the depth estimate will be reasonable and the structural index should be constant over the entire area for which the response is anomalous. Estimate will be reasonable and the structural index should be constant over the entire area for which the response is anomalous.

3. Results and Discussion

3.1. Total Magnetic Intensity Map

The total magnetic intensity map (TMI) of the study area in lower Sokoto sedimentary basin produced from this study using Oasis Montaj version 7.1 is as shown in (Figure 2). The TMI map of lower Sokoto sedimentary basin can be divided into three main sections, though minor depressions
exist scattered all over area. The northern part of some area in lower Sokoto basin is characterized by high magnetic intensity values ranges from 7883 to 7900. Whereas the southern part is dominated by low magnetic intensity values ranges from 7792 to 7860. The two sections are separated by a zone characterized by medium magnetic intensity values area depicted by yellow-orange colour. These high magnetic intensity values, which dominate the northern part in some area of the study area in lower Sokoto 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 some part of the study area in general, appears to increases from south to north.

Fig. 2: Total Magnetic Intensity Map of the Study Area

3.2. Residual Magnetic Intensity Map

Fig. 3 is the residual magnetic intensity map of the study area. The residual map is characterized with positive and negative magnetic susceptibility values. The pink and red colour
represents the high positive values while the blue colour represents high negative values. The pale-green and yellow colour represent the lower negative and lower positive magnetic values respectively. The magnetic intensity values ranges from -10 nano Tesla to 40 nano Tesla. Negative magnetic intensity values are more predominant in the southeast section of the study area while the northwest has more of positive magnetic intensity values. Northeast–Southwest trends are observed in the north central part of the TMI map. The blue color in the southeast indicating the area of higher sedimentation around sheet 117 (konkoso) in the study area with the prospect of hydrocarbon accumulation.

![Residual Magnetic Intensity Map](image)

**Fig. 3:** Residual Magnetic Intensity Map of the study area

### 3. Parameter Imaging (SPI)

The result of the Source Parameter Imaging (SPI) shown in figure 4 has its highest sedimentary thickness of about 2.8 to 3 km which could be found at central part of Konkoso, Kaoje and at northern parts of Kaoje could be sufficient for hydrocarbon prospecting. The shallow sedimentary thickness could also be found predominantly at Shanga, Yelwa and northern part at Konkoso and Kaoje at west eastern part. Oasis montaj software version 7.1 shows the depth values of Kaoje ranges from 2.2 km to 2.8 km, Shanga depth values varies from 1.2 km to 2.4 km, while Konkoso has depth of 2.3 km to 2.6
km, lastly Yelwa has the mean depth of 2.5 km. One important significance of this result is in its consideration of hydrocarbon prospect of the basin. If all other conditions for hydrocarbon accumulation are favourable, and the average temperature gradient of 1°C per 30m which obtains in the Niger Delta is applicable then the maximum thickness of sediments to achieve the threshold temperature of 115°C for the concealment of oil formation from organic remains (Wright et al., 1985) would be 2.3 km. The result obtained shows that the prospect for hydrocarbon accumulation may be promising. Detailed seismic survey should be carried out around Kaoje, and Konkoso, these areas were suggested as having the highest sedimentary thickness of about 2.8 to 3 km, as this may probably determine the presence of hydrocarbon.

![Figure 4](image)

**Fig. 4:** Source Parameter Imaging Depths Map of the Study Area

### 4. Conclusion

Presence of hydrocarbon and its potential is enhanced by the thickness of the sediments of the basin, and also by the kind of geological structures existing within the basement that form traps for oil and gas.

Based on the results of source parameter imaging identified on the Total Magnetic Intensity (TMI) of some part of lower Sokoto sedimentary Basin it can be concluded that there is a sedimentary thickness of about 2.8 km around Kaoje and Konkoso areas. The shallow sedimentary thickness could
also be found predominantly at Shanga, Yelwa and Northern part at Konkoso and Kaoje at Western part of the study area. The depth varies from 2.214 km to 2.8 km, 721 km 2.44 km, 2.34 km to 2.69 km, and 1.8 km in Sheet 95, 96, 117, and 118 respectively.

References

Geology of the study area after Nigerian Geological Survey Agency (NGSA 2005)