DETERMINATION OF DEPTH TO MAGNETIC SOURCE OVER PART OF MONGUNU AND ENVIRON USING SOURCE PARAMETER IMAGING FROM HIGH RESOLUTION AEROMAGNETIC DATA

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Abstract

This study focuses on determination of sedimentary thickness using Source Parameter Imaging (SPI) to interpret high resolution aeromagnetic data over part of Mongunu and environ northeast Nigeria for possible hydrocarbon presence. The study area is covered by four aeromagnetic data sheets: 45 (Dubumbali), 46 (Monguno), 67 (Masu) and 68 (Marte), bounded by latitude 12^0 N - 13^0 N and longitudes 13^0 E - 14^0 E with an estimated total area of 12,100 km^2. Polynomial fitting method was adopted for the regional-residual separation of the total magnetic intensity. The pre-processed grids dx, dy and dz from residual grid were used as input grids to calculate the depth to magnetic source point (SPI). The result of the study shows a minimum sedimentary thickness of 1.5 km and this could be found at the extreme south-eastern part of the study area which correspond to Marte town and maximum sedimentary thickness of 3.50 km which could also be found at the Southwestern part of the study area around Masu town. The maximum sedimentary thickness of 3.50 km around Masu town, southwestern part of the study area may be sufficient for the presence of hydrocarbon maturation and accumulation in the study area.

Keywords: Sedimentary thickness, Source Parameter Imaging, Aeromagnetic data, Polynomial fitting and Hydrocarbon

INTRODUCTION

The continuous search for mineral and petroleum (hydrocarbon) deposit has been a major challenge that will continue to be faced not only in Nigeria but also all over the world. Nigeria is a country that is blessed with lots of mineral resources, but yet to explore most of these resources. Nigeria is being faced with some economical challenges, political challenges, and reliance on some specific mineral deposit leading to the negligence in some others, which may yield large economic potentials to the country at large.

Considering the fact that the hydrocarbon (petroleum) which presently has been a great source of revenue generator for the country. These resources will not always be there forever, holding to the fact that it is a source of energy that is non-renewable in nature, and might one day in the nearest future get exhausted, as a result of continuous exploitation. To that effect, attention needs to be shifted to other basins (sedimentary basins) which have some of the geological potentials of having some useful minerals, be it solid minerals or hydrocarbons.

Recently, some countries have been discovering petroleum from their inland basins, which are similar to that of Nigeria's inland basin in terms of time. Subsequently the Nigerian government through the Nigeria National Petroleum Co-operation (NNPC) and other oil companies deem it necessary to run heavy investments in the inland basins, which have being prospected for hydrocarbon and other minerals. This till today remains exclusive (Salako and Udensi, 2013). Such a Basin is the Benue Trough, which comprises of, Upper, Middle and Lower Benue Troughs and has the prospect of not just hydrocarbon deposit but also some economic minerals. Never the less, effort and money is still been pumped into the research carried out, based on reconnaissance for minerals and hydrocarbon being prospected in the area (Salako, 2014).

The geophysical method that is being employed in this work is the magnetic method, using aeromagnetic data to study the depth to basement estimation over Lafia area, located at the middle Benue Trough. This study is aimed at determining the sedimentary thicknesses in the study area and depths to different magnetic source using the high resolution aeromagnetic data obtained from the airborne magnetic survey in Nigeria carried out between the year 2005 and 2009 by Nigerian Geological Survey Agency. Image processing of the source parameter grids enhances details and provides maps that help interpretation even by non-specialist (Nwosu, 2014). The method assumes either a 2-D sloping contact or a 2-D dipping thin-sheet model and is based on the complex analytic signal.

Location and Geology of the Study Area

The study area is part of Bornu Basin North Eastern, Nigeria is bounded by latitude 12^0 N - 13^0 N and longitudes 13^0 E - 14^0 E with an estimated total area of 12,100 km^2 (Figure 1a). The study area is endowed with rock mineral base resources such as clay, salt, limestone, kaolin, iron ore, uranium and mica. Petroleum is prospected intensively on the shore of the Lake Chad. Commercial activity is very significant in the state. The study area is connected to other neighbouring states and neighbouring countries by air, road and rail which makes commercial activities easier in the area.

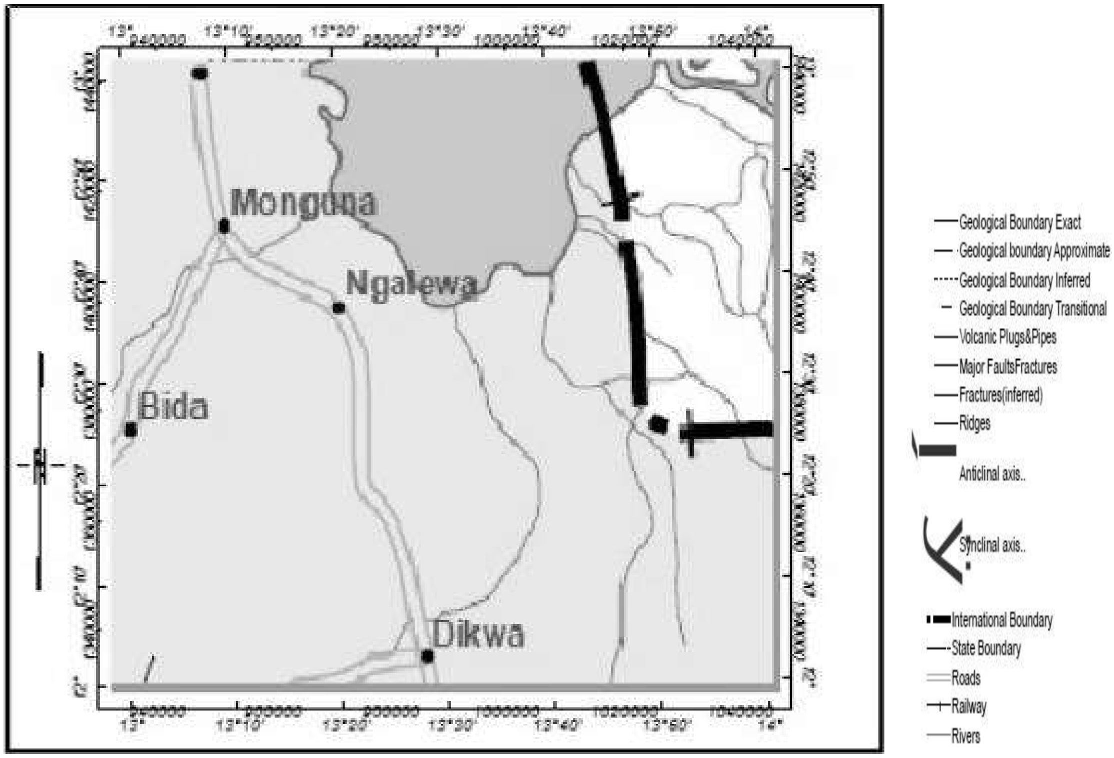

Figure 1a: Extracted Geologic map of the study Area (Adapted from NGSA, 2006)

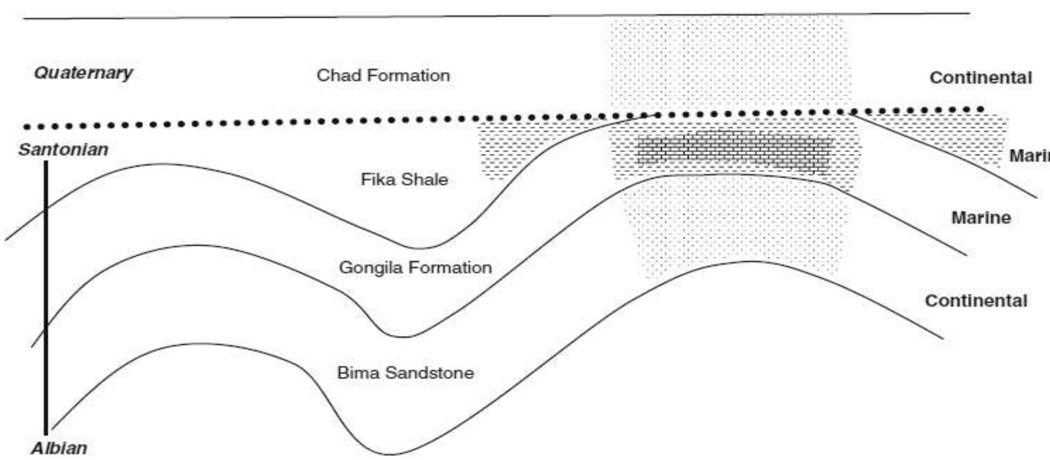

Figure 1b: Generalised Stratigraphic Sequence of Bornu Basin, Nigeria (Adapted from Obaje, 2004).

Geologically, the Bornu basin has been explained as a broad sediment-filled broad depression straddling North-eastern Nigeria and adjoining parts of the Republic of Chad (Obaje, 2004). The sedimentary rocks of the area have a cumulative thickness of over 3.6 km and rocks consist of thick basal continental sequence overlaid by transitional beds followed by a thick succession of Quaternary Limnic, fluviatile and eolian sand and clays (Lawal *et al.*, 2014). The stratigraphy sequence shows that Chad (Figure1b), Kerri-Kerri and Gombe

Formations have an average thickness of 130 to 400 m. Below this formations are the Fika shale with a dark grey to black in colour, with an average thickness of 430 m. Others are Gongila and Bima Formations with an average thickness of 320 m and 3,500 m, respectively (Odebode, 2010).

Materials and Method

Four high resolution aeromagnetic maps (HRAM) were acquired, assembled and interpreted. These maps were obtained as part of the nationwide airborne survey carried out and sponsored by the Nigerian Geological Survey Agency between the year 2005 and 2009. The airborne survey was carried out for the Nigerian Geological Survey Agency by Fugro airways services, the surveys was flown at 500 m line spacing and at an average flight elevation of 80 m along NW – SE direction, and published in form of grid (digital form) on 30` by 30` sheets. The maps are on a scale of 1:100,000 and half-degree sheets contoured mostly at 10 nT intervals. The geomagnetic gradient was removed from the data using the International geomagnetic Reference Field (IGRF) 2005. The total area covered was about 12,100 km^2. The actual magnetic intensity value of 33,000 nT which was reduced for handling and must be added to the value of magnetic intensity value before plotting so as to get the actual value of the magnetic intensity at any point. The four maps (sheets): 45 (Dubumbali), 46 (Monguno), 67 (Masu) and 68 (Marte). covering the study area were combined and re-gridded to obtain the super map of the study area using Oasis Montaj (Figure 2). The total intensity map (TMI) or super map was subjected to regional/residual separation using polynomial fitting method of order 1. The residual map (Figure 3) obtained shows both positive and negative magnetic intensity values which ranges from -120.0 nT to 90.3 nT.

The pre-processed grids dx, dy and dz from residual grid was used as an input grid to calculate the source parameter imaging. This process was carried out using the algorithm in the Oasis Montaj software. SPI method makes the task of interpreting magnetic data significantly easier as shown by the SP images generated from residual field data of the studied area (Figure 4a). The result of the SPI shows that the maximum sedimentary is more pronounced at the Masu eastern part of the study area and this agrees with the analytic signal map (Figure 4b) produced from this study area.

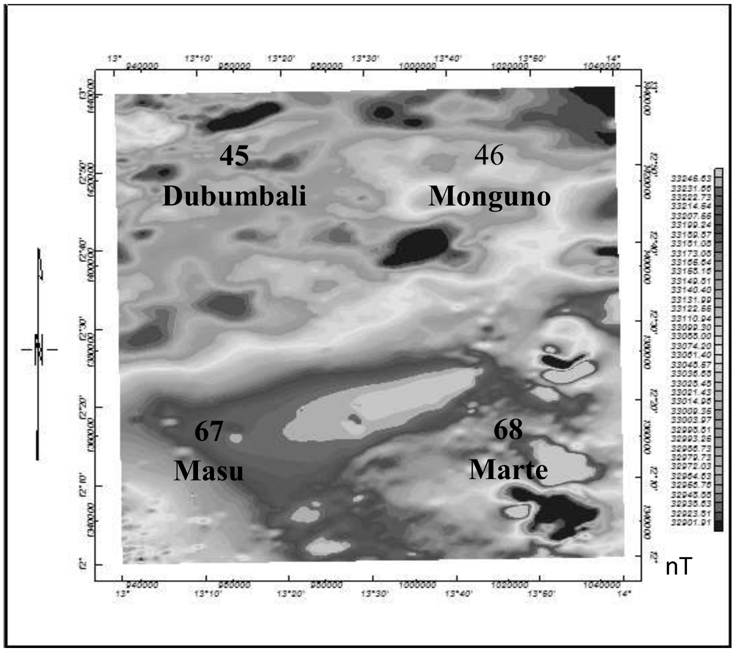

Figure 2: Total Magnetic Intensity (TMI) map of the study area

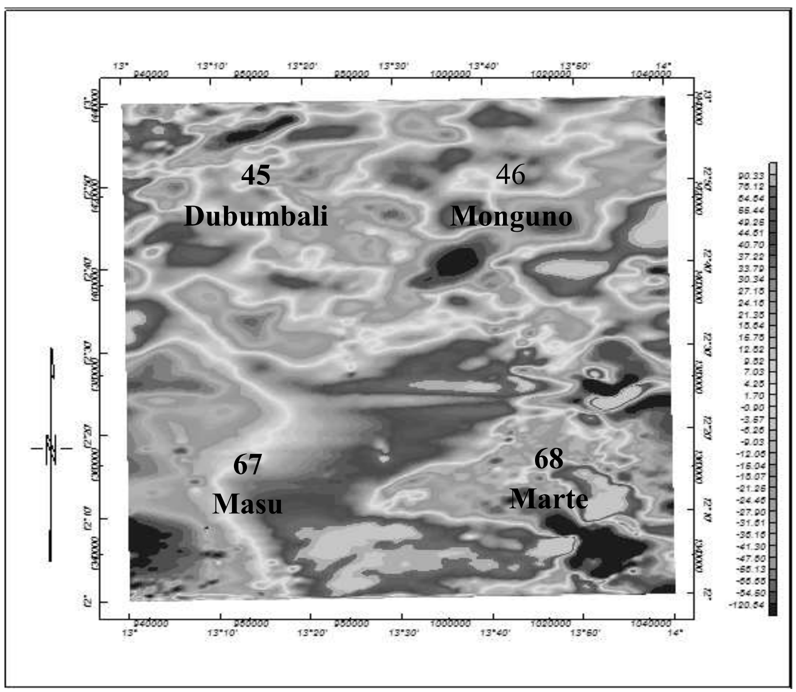

Figure 3: Residual Map of the Study Area

Estimation of Depth to magnetic Source Using SPI^{TM}

The Source Parameter Imaging (SPI^{TM}) is a technique using an extension of the complex analytical signal to estimate magnetic depths. This technique developed by Thurston and Smith (1997) and Thurston *et al*. (1999,

2002) sometimes referred to as the local wavenumber method is a profile or grid-based method for estimating magnetic source depths, and for some source geometries the dip and susceptibility contrast. The method utilizes the relationship between source depth and the local wavenumber (k) of the observed field, which can be calculated for any point within a grid of data via horizontal and vertical gradients Thurston and Smith, (1997). The depth is displayed as an image. The original SPI™ method (Thurston and Smith, 1997) works for two models: a dipping thin dike and a sloping contact. The local wavenumber has maxima located over isolated contacts, and depths can be estimated without assumptions about the thickness of the source bodies (Smith *et al.*, 1998). Solution grids using the SPI technique show the edge locations, depths, dips and susceptibility contrasts. The local wavenumber map more closely resembles geology than either the magnetic map or its derivatives. The SPI method requires first- and second-order derivatives and is thus susceptible to both noise in the data and to interference effects.

In 1997, Thurston and Smith developed source parameter imaging and used it to estimate the depth from the local wavenumber of the analytical signal. The analytical signal $A_1(x, z)$ is defined by Nabighian (1972) as:

$$A_1(x,z) = \frac{\partial M(x,z)}{\partial x} - j\frac{\partial M(x,z)}{\partial z}, \quad (1)$$

where M(x,y) is the magnitude of the anomalous total magnetic field, j is the imaginary number, z and are Cartesian coordinates for the vertical direction and horizontal direction respectively. Nabighian (1972) reveal that horizontal and vertical derivatives comprising the real and imaginary parts of the 2D analytical signal are related as follows:

$$\frac{\partial M(x,z)}{\partial x} \Leftrightarrow \frac{\partial M(x,z)}{\partial z}, \quad (2)$$

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

$$k_1 = \frac{\partial}{\partial x}\tan^{-1}\left[\frac{\partial M}{\partial z}\Big/\frac{\partial M}{\partial x}\right], \quad (3)$$

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

$$\frac{\partial^2 M(x,z)}{\partial z\,\partial x} - \frac{\partial^2 M(x,z)}{\partial^2 z}, \quad (4)$$

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

$$A_2(x,z) = \frac{\partial^2 M(x,z)}{\partial z\,\partial x} - j\frac{\partial^2 M(x,z)}{\partial^2 z}, \quad (5)$$

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

$$k_2 = \frac{\partial}{\partial x}\tan^{-1}\left[\frac{\partial^2 M}{\partial^2 z}\Big/\frac{\partial^2 M}{\partial z\,\partial x}\right], \tag{6}$$

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.

Nabigbian (1972) gives the expression for the vertical and horizontal gradient of a sloping contact model as:

$$\frac{\partial M}{\partial x} = 2KFcsin\,d\frac{h_c\cos(2I-d-90)+xsin(2I-d-90)}{{h_c}^2+x^2}, \tag{7}$$

$$\frac{\partial M}{\partial z} = 2KFcsin\,d\frac{x\cos(2I-d-90)+h_c sin(2I-d-90)}{{h_c}^2+x^2}, \tag{8}$$

where K is the susceptibility contrast at the contact, F is the magnitude of the earth's magnetic field (the inducing field), $c = 1 - cos^2 isin^2\alpha$,$\alpha$is the angle between the positive x-axis and magnetic north, i is the ambient-field inclination, $tanI = sini/cos\alpha$d is the dip (measured from the positive x-axis), *hc* 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

$$M(x,z) = 2KF_{cw}\frac{h_1\sin(2I-d)+xcos(2I-d)}{{h_c}^2+x^2}, \tag{9}$$

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

$$M(x,z) = 2KFS\frac{sini}{sinr}\frac{({h_h}^2-x^2)\cos(2I-180)+2xh_h\sin(2I-180)}{({h_c}^2+x^2)^2}, \tag{10}$$

Murthy and Mishra, S is the cross-sectional area and h_h is the depth to the centre of the horizontal cylinder.

Substituting (7), (8), (9) and (10) into the first- and second- order (i.e. (3) and (6) respectively) local wavenumbers, we obtain, after some simplification, a remarkable result as:

$$k_1 = \frac{(n_k+1)h_k}{{h_k}^2+x^2}, \tag{11}$$

and

$$k_2 = \frac{(n_k+2)h_k}{{h_k}^2+x^2}, \tag{12}$$

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 number are independent of the susceptibility contrast, the dip of the source and the inclination, declination, and the strength of the earth's magnetic field.

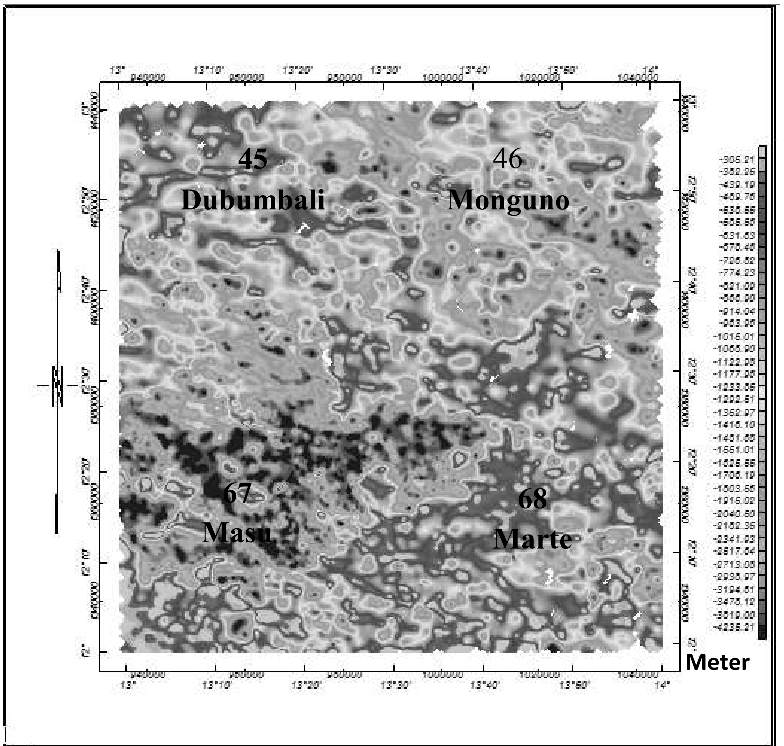

Figure 4a: Source Parameter imaging Map

Result and Discussion

The result of source parameter imaging of the aeromagnetic data of the study area (Mongunu and Environ), Figure 4a, has revealed two magnetic depth source; maximum depth (deep blue coloured) ranges from 1910.2 m and 3203 m with an average depth of 3511 m (3.50 km) and the minimum depth (light green and orange coloured) ranges from 165 m and 1421 m with an average depth of 1503.5 m (1.50 km). The deep blue colour represent areas with deep lying magnetic bodies hence with thicker sedimentary cover with an average depth of 3.50 km could be viewed as the magnetic basement depth of the studied area which might favour hydrocarbon maturation and accumulation. This result was corroborated with the result of the analytical signal (Figure 4b) where the least magnetic amplitude observed at the south-eastern part of the area agreed with the area of highest sedimentary thickness in Figure 4a. The maximum depth to magnetic basement is more pronounced around the western part of the study area which corresponds to Masu town. This result also agreed with other workers in the area like, Lawal *et al*, (2014), Okonkwo *et al.* (2012) , Lawal *et al.* (2007), Isogun (2005) and Nwankwo *et al*, (2013) Salako and Udensi (2013) Nur (2001), Likasson *et al.* (2005) and Salako

(2014). The minimum depth to magnetic basement depicted with orange colour at the extreme south-eastern part of the study area might be as a result of intrusion into the sedimentary basin.

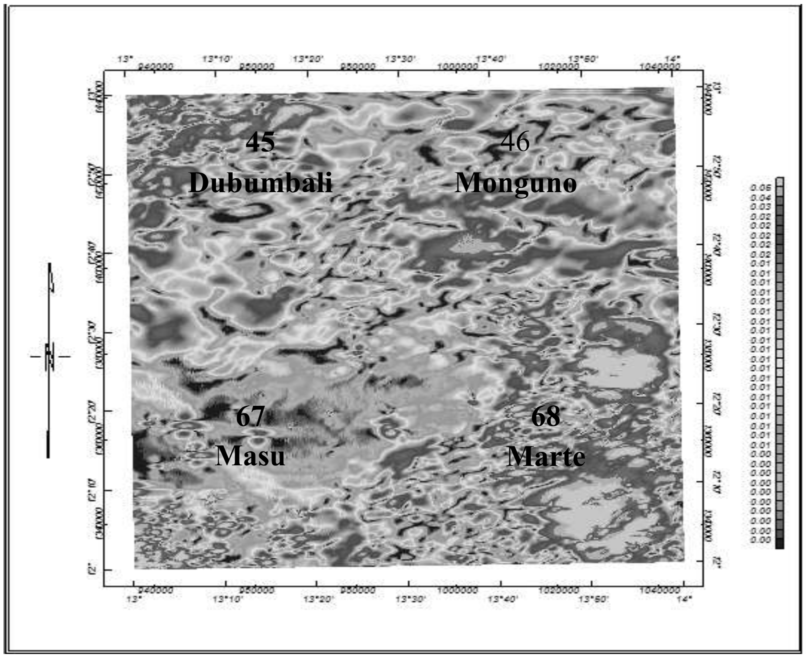

Figure 4b: Analytic Signal Map of the Study Area

Conclusion

The result acquired from this research work agrees with those of the other researchers who have used other depth estimating techniques and the previous old data, however, this could be more reliable and precise due to the nature of high resolution of the 2009 data over than the 1970s data in terms of terrain clearance, and line spacing. The old map requires digitization which is stressful and could introduce error unlike the 2009 data that is in digitized form, different errors have been corrected using improved software and technique. The SPI have estimated depth comparable with that from spectral and other technique and this depth values over part of Mongunu and environ particularly Masu town is an indication that hydrocarbon prospecting should be intensified in this area since the sediment over the area are sufficient for hydrocarbon maturation and accumulation.

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