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Characterization of Spectral Depth to Buried Magnetic Rocks over Part of Upper Benue Trough, Nigeria Using Aeromagnetic Data

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Abstract

A statistical method of spectral analysis was employed in this study to determine the depths to recorded magnetic sources over part of Upper Benue Trough, Nigeria, using aeromagnetic data. The area lies between Latitudes 9° 00' N to 10° 00' N and Longitudes 11° 00' E to 12° 00' E and covered by four Index Map Sheets of Kaltungo (173), Guyuk (174), Lau (194) and Dong (195), of 1/2° x 1/2° each with total area of approximately 12,100 km^2. The aim of this research is to determine the source(s) of magnetic anomalies over buried rocks and estimate the depths of their origin with a view of making informed suggestions as regards hydrocarbon prospectivity of the area. A total number of 1369 data points covering the entire study area, systematically acquired was obtained in soft copy from the Nigerian Geological Survey Agency of Nigeria, Abuja and used for this work. Oasis Montaj was used to carry out residual-regional anomaly separation based on First Order Polynomial Fitting. The depths to buried magnetic source rocks were then determined from the Slopes of the plots of logarithm of spectral energy against frequency using the Slope Plot Program. Results show that the high/strong magnetic anomalies are oriented northeast-southwest and flanked on the northwestern side by low and southeastern side by very low magnetic anomalies respectively. The magnetic anomalies also originated from two sources; the first (shallow source) from depths not exceeding 1.0 km and believed to be due to intrusive rock bodies in the basin while the second (deeper source) which originated from the magnetic basement lies at depth not greater than 3.25 km. The sedimentary cover in the area is generally thin and associated with many intrusive rock bodies.

Key Words: Depth to basement, Magnetic anomaly, Source rocks, Spectral analysis, Upper Benue Trough

1. Introduction

The exploration for oil and gas in the offshore of the Niger delta basin has led to the tightening of supply due to increasing cost of operations (Lar, 2015). In order to bridge the supply gap as well as reduce cost, emphasis by the Federal Government of Nigeria is now laid on the search for oil and gas in the inland basins of the country. The Upper Benue Trough (UBT) therefore is one of those inland basins in Nigeria suspected to have high potential for hydrocarbon. Although, a series of attempts has been made by experts in the oil/gas industry since the 1950s to search for oil and gas in the Nigerian inland basins including the UBT, there has been no reliable data that could prove commercial occurrence anywhere except on mere assumptions. In other words, there are insufficient geologic and geophysical information as regards the occurrence and distribution of these natural resources in these basins. Most of the research work done in this area was more geologic than geophysical.

Determination of the depth to the source of recorded magnetic anomalies is generally equivalent to determining the thickness of the sedimentary section. Since oil occurs only in sedimentary rocks, a reliable determination of the depth to the basement rocks gives a measure of the volume of sediments available in a given sedimentary basin and is a first limitation on its potential as source of oil (Nettleton, 1976). To achieve a preliminary research success on hydrocarbon prospecting in a sedimentary basin, there is need to acquire, process and interpret aeromagnetic data covering the entire area as well as gravity data in order to estimate areas of thick sedimentary piles which are normally favorable for trap formation and hydrocarbon accumulation (Obaje, 2015).

The area is bounded by Latitudes 9° 00' N to 10° 00' N and Longitudes 11° 00' E to 12° 00' E within the UBT, Nigeria (Figure 1) and covered by four index maps of Kaltungo, Guyuk, Lau and Dong sheets respectively each of 1/2° x 1/2°. It has an area extent of approximately 12,100 km^2.

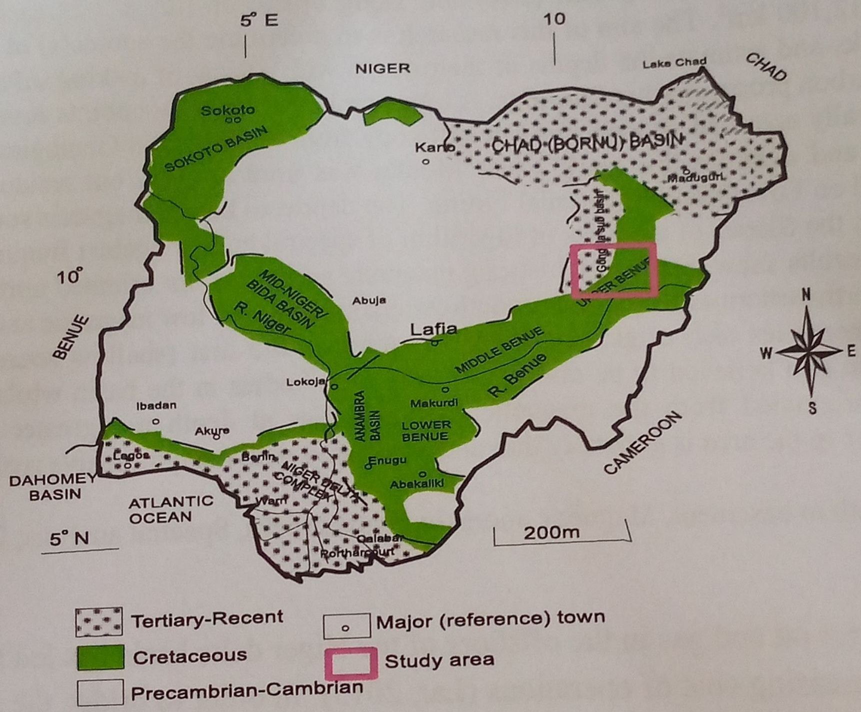


Figure 1: The Geological Map of Nigeria and the Study Area (After Obaje, 2009).

2. Literature Review

The area consists geologically of older rocks surrounded by younger sedimentary rock units-Kaltungo inliers. The basement includes rocks of the ''Older Granites'' series (Carter *et al.*, 1963) emplaced during the Pan-African orogenesis, around 600±70 Ma (Van Breeman *et al.*, 1977; Tubosun, 1983). The Kaltungo inlier and the surrounding Cretaceous deposits are characterized by the abundance of Tertiary intrusions and the magnetic anomalies are very strongly oriented in a N50E direction (Popoff *et al.*, 1983). The contours of the magnetic basement are in good conformity with the geological boundaries of the basement and the volcanic bodies are mainly oriented in the NE-SW, NNE-SSW and NW-SE directions forming concentrations localised on the eastern border of the Gongola branch and around the Kaltungo inlier (Benkelil *et al.*, 1985). The sedimentary series comprises the continental sandstone and transitional sandstone-shale sequence typified by Bima and Yolde Formations respectively while the marin e facies of shale and limestone which are marked by Pindiga Formation are all Cretaceous-Tertiary (146-24 Ma) in age (Whiteman, 1982; Benkhelil and Robineau, 1983).

In the Gombe arm of the UBT, (Osazuwa, 1978) showed that the thickness of sediments appears to be not greater than 2.00 km in view of the Kaltungo basement inlier and (Shemang *et al.*, 2005) also reported the existence of intra-basin intrusive bodies of high density in the trough at depth between 0.50 to 2.00 km while (Onuba *et al.*, 2008) showed that the deeper magnetic sources in the UBT range from 2.00 to 2.80 km.

3. Materials and Method

3.1 Data Acquisition/Processing

The composite aeromagnetic dataset was obtained from the Nigerian Geological Survey Agency, Abuja in soft copy. The data were acquired along a series of NW-SE flight lines with a spacing of 2 km and at average flight elevation of about 150 m while tie lines were kept at about 20 km interval. Residual-regional anomaly separation was done using the Oasis Montaj based on Least Squares First Degree polynomial fitting method. Under this method, an arbitrary trend surface representing the background values is superimposed on the entire field dataset. The regional values are then subtracted from the field data and the difference gives the residual values. The residual-regional anomaly was carried out in order to obtain the anomaly of interest (residual) which was analyzed for the determination of depths to recorded magnetic sources.

3.2 Estimation of Depth to Magnetic Source Rocks of the Study Area

Spector (1968) and Spector and Grant (1970) proposed that spectral analysis of residual magnetic field data can be used to determine the depth to the buried magnetic source rock. The residual field intensity values are used to obtain a two-dimensional Fourier series consisting of various wave numbers (frequencies) which characterise the anomalies. It has been recognised that a statistically-oriented approach is preferable because more than one anomaly can be used to determine the depth to the buried magnetic rock and mean depth values to major units of the buried magnetic rocks. This approach has been found to yield good estimates of mean depth to basement underlying a sedimentary basin (Hahn *et al.*, 1976; Shehu, 2003). Spector & Grant (1970) model assumes that an uncorrelated distribution of magnetic sources exists at a number of depth intervals in a geologic column. The evolution of spectral analysis has some important precursors, by which one tries to present data only in a simple 2-D format. The most important of these precursors is the harmonic analysis or Fourier series expansion of a given time series of data. According to Fourier theorem, any function f (t) satisfying certain restrictions can be expressed as a sum of infinite number of sinusoidal terms. To study the characteristics of the residual field, the data is first transformed from space to frequency domain and then their frequency characteristics are analyzed. For the purpose of analysing aeromagnetic maps, the subsurface is assumed to consist of a number of ensembles of rectangular, vertical-sided parallelepipeds. If there are two sets of sources then they can be recognised by a marked change in spectra decay rate. The energy spectrum of the double ensemble will then consist of two parts; the first which relates to the deeper sources, is relatively strong at low frequencies, and decays away rapidly. The second which arises from the shallower ensemble sources, dominates the high frequency end of the spectrum.

In general case, the radial spectrum may be conveniently approximated by straight line segments, the slopes of which relate to the depths of the possible magnetic layers (Spector and Grant, 1970; Hahn *et al.,* 1976). The power spectrum derived from a 2-D dataset such as a grid of residual magnetic data, also has inherently a 2-D form. If the frequency unit is in cycles per kilometre, the mean depth of burial of the ensemble is given by:

$$Z=-\frac{m}{4n} \qquad (1)$$

where m is the slope of best fitting straight line.

It has been found (Pal *et al.,* 1978) that in the use of spectral approach to magnetic source determinations, the error in depth prediction increases with the depth of source and is also related to the map size. The map size required for adequate results should be much larger, (about 10 times) the required target depth. The low frequency components in the energy spectrum are generated from the deepest layers whose locations are most likely in error thus, it is advisable in the general method here to ignore the first few points in the energy spectrum.

The study area was divided into nine (9) blocks/cells along specific longitudes and latitudes for spectral depth analysis. The blocks were not overlapping because at the boundary of each with the other, the magnetic values were summed and the average value used. The composite residual magnetic dataset was fed into the Oasis Montaj environment and the corresponding energy spectrum for each cell was obtained. The logarithm of the spectral energy for each block/cell was then plotted as a function of frequency of the ensemble of the cell using Slope Plot Program. The slopes of the first and second segments of the plot were respectively calculated and displayed automatically based on the best line of fit chosen (Energy Spectra of SPEC 1) is shown in Figure 2. From the slopes, the depth to the shallow magnetic source and that to the deeper source were respectively estimated using the relations below and the results shown in Table 1.

$$z_1=-\frac{m_1}{4\pi} \qquad (2)$$

$$z_2=-\frac{m_2}{4\pi} \qquad (3)$$

where $_1$ and $_2$ are slopes of the second and first segments of the plot while $_1$ and $_2$ correspond to the shallow and deeper magnetic source depths respectively. The coordinates of each spectral depth point were obtained by summing the values of the bounding latitude and longitude respectively and averaging it. The deeper and shallow layer depths were later contoured respectively using SURFER Program.

4. Results and Discussion

4.1 The Residual Map

A close look at the residual anomaly map (Figure 3) shows that the high magnetic anomalies are oriented NE-SW, NNE-SSW and flanked on both side by regions of low anomalies in the NW and very low on the SE side respectively. These NE-SW, NNE-SSW orientations of high anomalies are believed to be structurally-controlled probably due to a high basement relief or a fracture zone in that direction. Nsikak *et al.* (2000) generally believed that there would always be a magnetic susceptibility contrast across a fracture zone due to oxidation of magnetite to haematite and /or infilling of fracture planes by dyke-like bodies whose susceptibilities are different from those of their host rocks. Such geological features may appear as thin elliptical closures or nosing on an aeromagnetic map. This confirms the work of (Benkhelil, 1982^{b}) that a major fault cutting across the Kaltungo Inlier has been observed in the field and mapped in detail (Popoff *et al.,* 1983) using Landsat and SLAR imageries and field data. The regions of low anomalies on the NE and that of the SE is strong indication that the basement here is much deeper. The high, distinct and sharp anomalies found within these regions of low and very low anomalies (pinkish colour) are indicative of intrusive rock bodies found within the sediments which corroborate with (Popoff *et al*., 1983).

4.2 The Regional Map

The orientations of the anomalies on this map (Figure 4) are generally NE-SW, very similar to that of the residual map. This shows the background values of the anomalies which was filtered or separated from total field intensity values. It can be observed that the regional values increase from the NE part through the central region and at maximum in the SE fringe where the residual anomalies are very low. The contour interval on this regional map is 2 nanoteslas.

4.3 The Spectral Depth Map

The depths to recorded magnetic anomalies from this study characterise two sources; one from the shallow source and the other from deeper source respectively (Table 1). The first magnetic source originated from depth ranging from 0.6 to 1.00 km. The second source originated from depth ranging from 2.25 to 3.25 km. The first source characterizes magnetic anomalies arising from intra-basin intrusive bodies while the second sources are believed to be from the basement underlying the basin. However, according to (Shemang *et al.*, 2005), the depth to the shallow magnetic source is between 0.50 to 2.00 km while Osazuwa (1978) reported a maximum depth of 2.00 km to the basement and (Onuba *et al.*, 2008) put the depth to magnetic basement at 2.00 to 2.80 km. Since a measure of the depth to magnetic basement is equivalent to determining the volume of sediments that overlie it (Nettleton, 1976), the thickness of sedimentary cover in the study area varies from 2.25 to 3.25 km.

Both the 2-D and 3-D depth maps (Figure 5a & b) for the first magnetic sources indicate that the intrusive bodies occurred at much shallower level around NE, NW and the central region (Kaltungo and Guyuk) than the SE and SW (Lau and Dong) axes. Similarly, the 2-D and 3-D depth maps (Figure 6a & b) for the second magnetic sources appear to be dipping from Kaltungo and Guyuk regions towards Lau and Dong axes respectively confirming thicker sedimentary piles. The relief patterns of the 3-D maps therefore conform to the magnetic anomalies observed over the area.

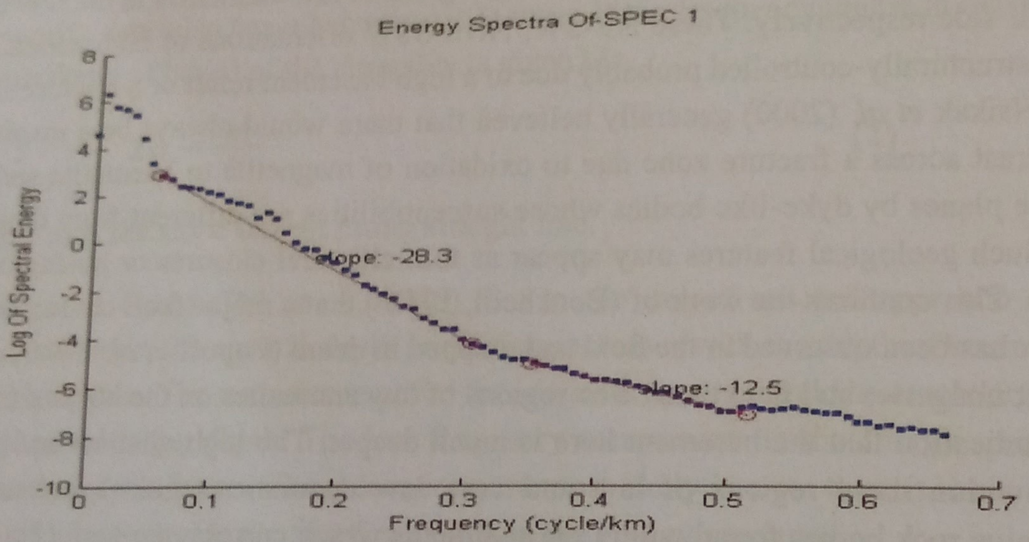


Figure 2: Energy Spectrum Plot for Depth Determination

Table 1: Magnetic Source Depth Estimates

Spec No.	Long. (⁰E)	Lat.(⁰N)	m_1	z_1 (km)	m_2	z_2 (km)
1	11.25	9.25	-12.50	0.99	-28.30	2.25
2	11.75	9.25	-11.80	0.94	-40.90	3.25
3	11.25	9.75	-7.57	0.60	-30.00	2.39
4	11.75	9.75	-8.41	0.67	-33.00	2.62
5	11.50	9.25	-11.00	0.87	-30.60	2.43
6	11.50	9.75	-8.60	0.68	-32.30	2.57
7	11.25	9.50	-10.00	0.79	-30.60	2.43
8	11.75	9.50	-8.85	0.74	-30.50	2.43
9	11.50	9.50	-8.22	0.65	-32.40	2.58

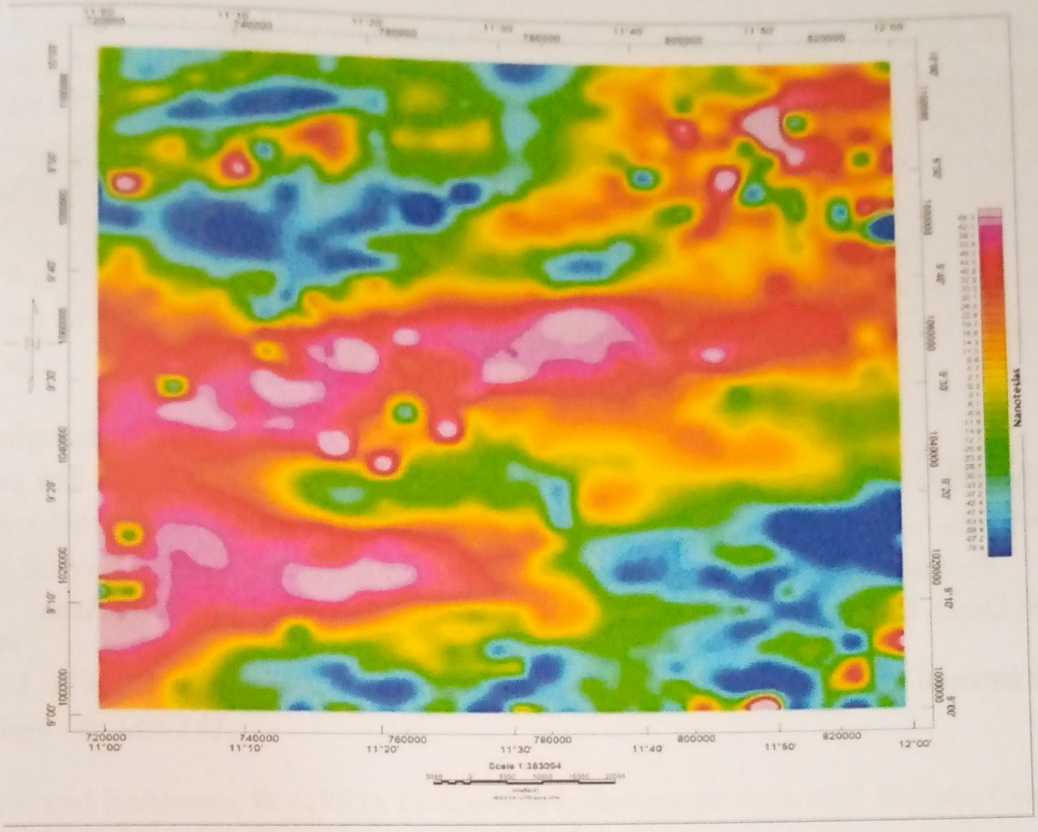


Figure 3: Residual Anomaly Map (Contour Interval = 20 nanoteslas)

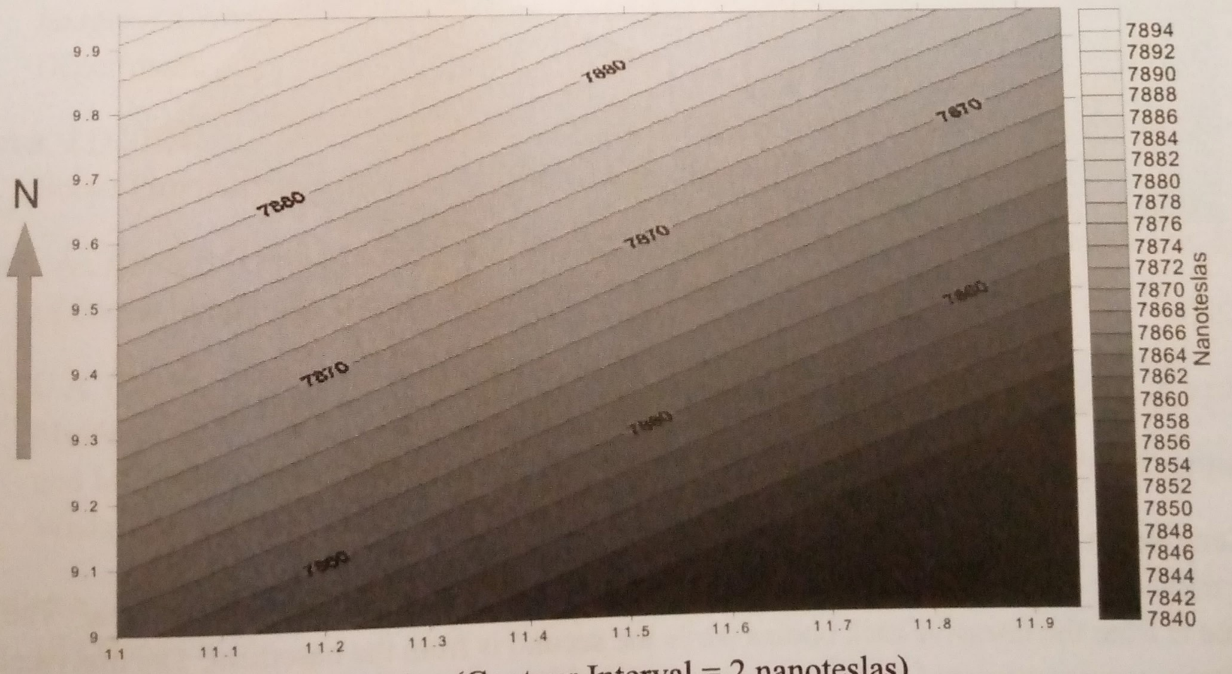
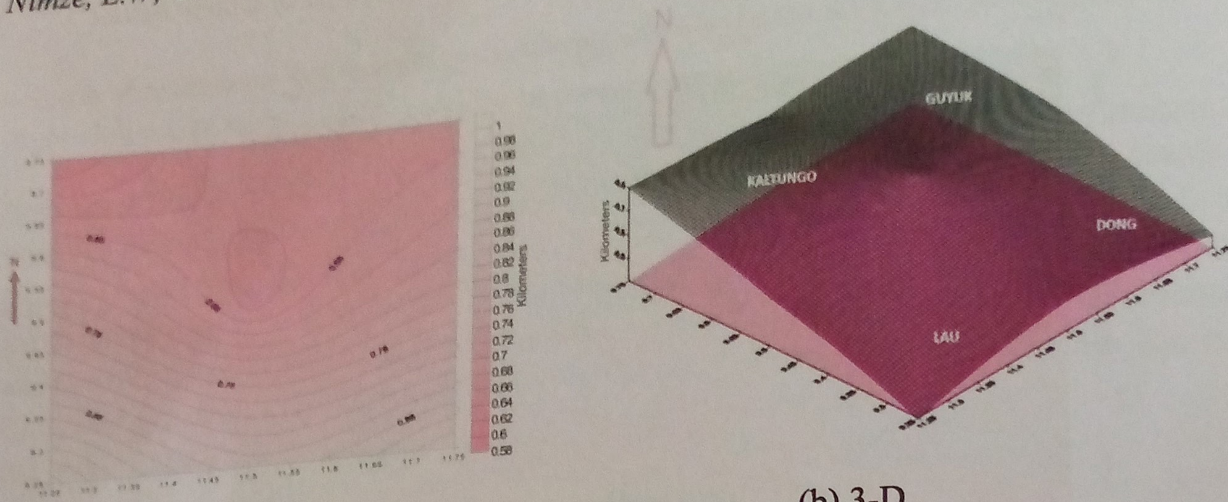


Figure 4: Regional Anomaly Map (Contour Interval = 2 nanoteslas)

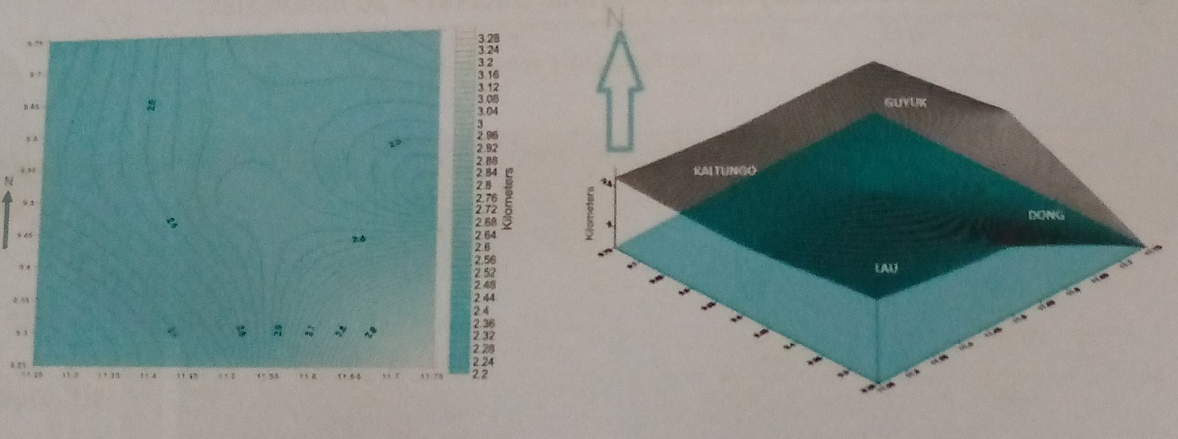


(a) 2-D

(b) 3-D

Figure 5: Depth Contour Maps of the Shallow Magnetic Source of the Study Area

(Contour Interval = 0.02 km).



(a) 2-D

(b) 3-D

Figure 6: Depth contour maps of the deeper magnetic sources of the study area

(Contour Interval = 0.02 km)

5. Conclusion

The magnetic anomalies observed over the study area originated from two sources. The first source is from the intrusive rock bodies while the second is from the basement. The first (shallow) magnetic sources occurred at depth not greater than 1.00 km while the source from the magnetic basement occurred at depth not exceeding 3.30 km. The intrusive bodies occurred as pockets almost all over the entire area but forming concentrations within the NE-SW trend. This NE-SW trend cutting across the study area is believed to be a fracture zone. The sedimentary cover is much thicker in the SE region than any other part of the study area i.e. around Dong. This part therefore is more prospective for hydrocarbon. However, the intrusive bodies that characterize the study area might have baked the hydrocarbon source rocks or driven off the hydrocarbon products. This is so because of the general lack of association of hydrocarbon with intrusions whose emplacement is usually accompanied with tremendous heat. On the other hand, the heat generated during the emplacement of these intrusive bodies might influence thermal maturation of the hydrocarbon source rocks.

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