DETERMINATION OF DEPTH TO BURIED MAGNETIC ROCKS UNDER THE LOWER SOKOTO BASIN, NIGERIA, USING AEROMAGNETIC DATA

A. A. Adetona*, E. E. Udensi* and A. G. Agelaga **
**Department of Physics, School of Science and Science Education, Federal University of Technology, Minna, Nigeria.*
***Department of Applied Science, Kaduna Polytechnic, Kaduna, Nigeria*
E-mail:tonabass@yahoo.com

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Abstract

Statistical spectral analysis of the residual magnetic field values is employed in this research to determine the depth to the magnetic basement rocks under the lower Sokoto Basin. The area of study lies between longitude 4° to 5° E and latitude 10°30' to 11°30' N. For this analysis the study area is divided into 49 sections allowing spectral depth determination at every 15km by 15km interval of the field. The spectral analysis reveals two prominent magnetic layers. The first layer depth varies from 0.22km to 0.96km with an average value of 0.457km; while the second layer depth varies from 0.46km to 1.96km with an average value of 1.45km. The first magnetic layer is attributed to lateritic ironstone, ferruginous sandstone and effect of surrounding basement rocks while the second layer is attributed to magnetic rocks intruded onto the basement surface, lateral discontinuities in basement susceptibilities and interbasement features like faults and fractures. The second layer depth thus represents the depth to basement in the area and this depth has an average value of 1.44km. This represents the average thickness of the sedimentary formation overlying the Basement Complex within the lower flange of the Sokoto Basin. The generalized depth to basement map produced reveals that the basin is generally shallow with a maximum depth of 1.93km. This depth estimates reduces the possibility of hydrocarbon accumulation. The magnetic depth estimates and the surface plot of the second layer depth reveal an irregular basement floor resulting from gentle folding of the basement rock.

Keywords: *Spectral depth, buried magnetic rocks and aeromagnetic data*

Introduction

The study area is part of the Sokoto Basin of Nigeria, Fig 1. one of the young (Mersozoic Tertiary) inland cratonic sedimentary basin of West Africa. The

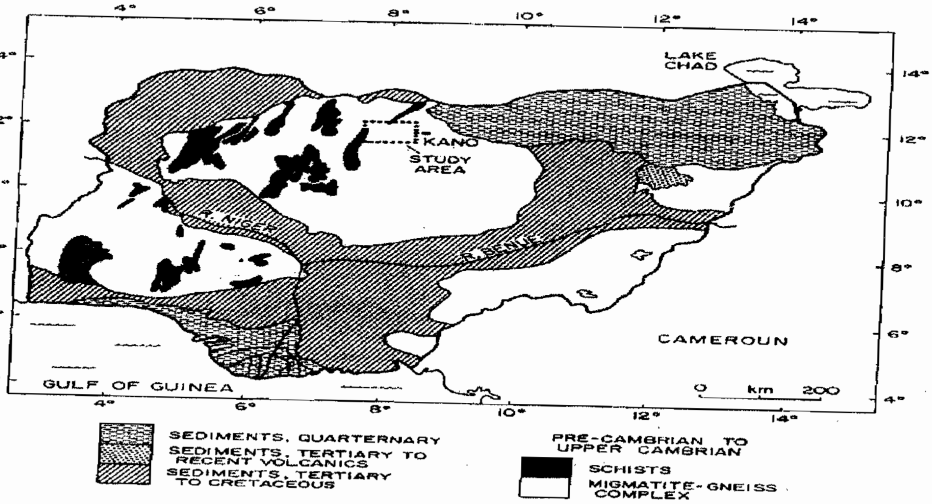

Fig (1) Simple geological map of nigeria showing the study area.

basin, like other intra-continental basins of the region and the African continent in general, developed by epeirogenesis warping or stretching and rifting of tectonically stabilized crust. These movements commenced around the beginning of the Paleozoic and continued until upper cretaceous, and are responsible for the South Western peroration of sediments deposited within the basin, Kogbe 1979 & 1981; Wright *et al;* 1985).

According to Jones (1948), the depositional history of the sediments of the basin can be summarized as follows:

1. A continental period represented by the Illo and Gundumi Formations. These beds are probably Lower Cretaceous and are certainly younger than Cenomanian.
2. A marine period commencing in the Moastrichtian into the Eocene, during which the Rima Group and the clay-shale and calcareous groups (Eocene) were laid down.
3. A movement of elevation (Alphine Orogeny) probably in the late Eocene times leading to the retreat of the sea and accompanied by gently folding.
4. A continental period represented by the Gwandu Formation, which is probably of upper Tertiary age.

Economic Geology

The most important economic mineral deposit in the "lower Sokoto basin" are the industrial minerals consisting of clays, ironstone and laterites including liquate radio-active minerals and salts.

The occurrence of laterite and ferruginized sandstone is widespread throughout the basin; these serves as a major source of raw materials for road construction. The cement factory is already utilizing limestone deposits from the Paleocene formations around Sokoto.

Theoretical Analysis

(a) Energy spectrum and depth of magnetic source

Consider the energy spectrum of the total magnetic field intensity anomaly over a single rectangular block. The expression for the energy spectrum transcribed in polar coordinates is given as follows (Spector and Grant, 1970):

$$\text{if } r = (u^2 + V^2) \text{ and}$$
$$\theta = \arc\tan (u/v), \qquad (1)$$

the energy spectrum E (r, θ) is given by

$$E(r, \theta) = 4^2 K^2 e^{-2hr} (1 - e^{-tr}) S^2(r, \theta)$$
$$R^2 T(\theta) R^2_k(\theta) \qquad (2)$$

where K/4ab is the magnetic moment per unit volume of the rectangular block. Here a and b are the width and length, K is the magnetic moment per unit depth.

$$S(r,\theta) = \frac{\sin(ar \operatorname{Cos}(\theta))}{arCos(\theta)} = \frac{\sin(br \operatorname{Cos}(\theta))}{brCos(\theta)}$$
$$R_T^2(\theta) = \left[n^2 + (1 \cos(\theta) + M \sin(\theta))^2\right], \qquad (3)$$
$$R_K^2(\theta) = \left[N^2 + (L \operatorname{Cos}(\theta) + M \sin(\theta))^2\right];$$

$$< ECr > \doteq 4\pi^2 K^2 < l^{-2hr} > < (1 - l^{-tr})^2 > < S^2(r) > \qquad (4)$$

$$< S^2(r) > = \frac{1}{\pi} \int_0^{\pi} \quad < S(r,\theta) > d\theta$$

The ensemble average depth h enters only into the factor.

$$< l^{-2hr} > = \frac{l^{-2hr} \sin h (2r\Delta h}{4r\Delta h} \qquad (5)$$

Spector and Grant (1970) obtained the expression for the ensemble average of the radial spectrum as L,m,n are direction cosines of the magnetic moment vector.

For depth estimations for magnetic field data this can be approximated to exp (-2hr) (Spector and Grant (1970)). The exp (-2hr) term is the dominant factor in the power spectrum.

The residual total magnetic field intensity values are used to obtain the two dimensional Forier Transform from which the spectrum is to be extracted from. The evaluation is done using an algorithm that is a two dimensional extension of the fast Fourier Transform

(Cooey and Tukey, 1965 Openheim and Schafer, 1975). Next, the frequency intervals are subdivided into sub-intervals, which lie within one unit of frequency range. The average spectrum of the partial waves falling within this frequency range is calculated and the resulting values together constitute the redial spectrum of the anomalous field (Hahn *et al;* 1976,Negi *et al;* Kangkolo 1996, Udensi, 2001).

Finally we plot the logarithm of the energy values versus frequency on a linear scale and locate the linear segments.

Each linear segment groups points due to anomalies caused by bodies occurring within a particular depth. If Z is the mean depth of a layer, the depth factor for this ensemble of anomalies is exp (-2ZK). Thus the logarithmic plot of the radial spectrum would give a straight line whose slope is 2Z. The mean depth of buried of the ensemble is thus given as.

$$Z=-m/2 \qquad (6)$$

(b) **Determination of spectral depths**

Residual total magnetic field intensity values are used to obtain the two dimensional Fourier Transform from which the spectral values are to be extracted.

Next, the frequency intervals are subdivided into subintervals which lie within one unit of frequency range. The average spectrum of all the partical waves falling within this frequency range is calculated. A plot of the logarithm of the energy values versus frequency consists of linear segments each of which groups points due to anomalies caused by bodies occurring within a particular depth, If z is the mean depth of a layer, the depth factor for this ensemble of anomalies is exp. (-2zk), where k is the magnetic moment per unit depth (Spector and Grant, 1970). Thus the logarithmic plot of the radial spectrum would give a straight line whose slope is 2z.

The use of the Discrete Fourier Transform introduces the problem of aliasing and the truncation effect (or Gibb's phenomenon). Aliasing can be reduced by the digitization interval (Bath, 1974). The truncation effect can also be reduced by applying cosine taper to the observed data before Fourier Tarns formation (Bath, 1974)

Source of Data for the Present Study

Four aeromagnetic map sheets numbers 94, 95,117 and 118, that cover Shanga Kwankoso Kaoje and Yelwa, respectively, were used. These maps are produced by the Geological Survey of Nigeria, which undertook the aeromagnetic survey of substantial part of Nigeria between 1974 and 1980. The data were collected at a nominal flight altitude of 152.4m along N-S flight lines spaced approximately 2 km apart. The maps are on a scale of 1:100,000 and half-degree sheets contoured mostly at 10nT intervals. A correction based on the International Geomagnetic Reference Field (IGRF) epoch date January 1, 1974 was applied to all the data.

Procedure

The procedures adopted for this study are outline as follows.

A total of four aeromagnetic maps covering the study area were digitized manually on a 38 by 38 grid system.

All the digitized maps were combined into a single "super map". This "super map" or composite aeromagnetic map of the study area formed the basis for further analysis and interpretation.

Spectral statistical analysis was applied to the residual field data to determine the depth to magnetic layers.

Results of depths obtained from spectral analysis were used to produce contour maps for the study area, also surface plot for the depths was produced, this will indicate areas of relative surface depressions and uplifts.

Each map was digitized on a 1.5 x 1.5 km^2 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 3km. Previous studies with crystal magnetic anomalies (Hall, 1968 and 1974, Udensi, 2001) shows that this spacing is adequate for the portrayal of and interpretation of magnetic anomalies arising from regional crustal structure, which are much wider than 6km and therefore lie below the frequency range for which computational errors arising from aliasing do not occur. After digitizing each aeromagnetic map, the data were recorded in a 38 by 38-codding sheet.

A simple computer program was used to arrange the resulting data in an x y z column where the x stands for the longitude value the y for latitude and the z for the magnetic field value. A computer package named suffer was used to contour the data to produce the composite aeromagnetic map of the study area. The emerging map, Fig.2, was contoured at an interval of 10nt.

Regional-residual separation

Two important disturbances can be observed on the picture that emerges from a composite magnetic map in fig. (2). These disturbances, which are different in order of sizes, are generally super imposed. The large features generally show up as trends, which continue smoothly over considerable distance. They are caused by deeper heterogeneity of the earth crust. These trends are known as regional trends.

Superimposed on the regional fields, but frequently camouflaged by them, is the smaller, local disturbances, which are secondary in size but primary in importance. These are the residual anomalies. These may provide direct evidence of the existence of reservoir type structures or mineral ore bodies.

For potential field data (such as magnetic and gravity) to be interpreted, the residual anomalies must be separated from the regional background field. The least

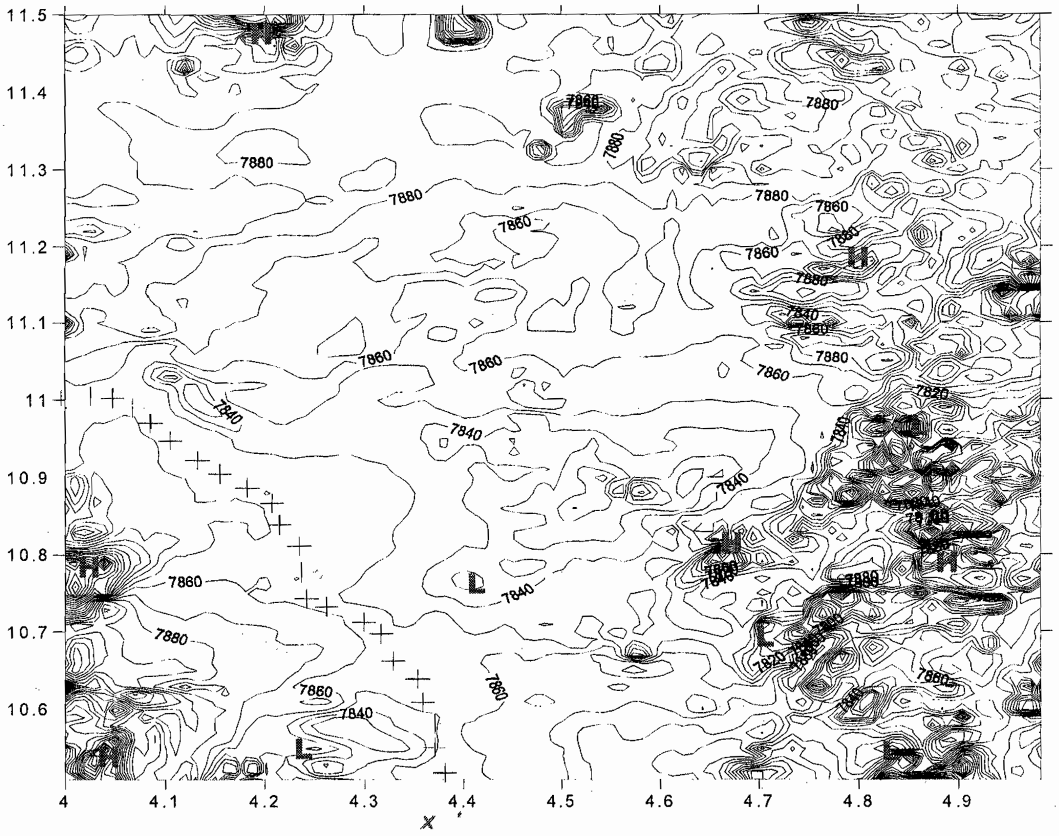

Fig. 2: Composite aeromagnetic map of part of lower Sokoto Basin showing magnetic Closures for highs as (H) and lows (L) Discontinuities (XX") contoured at 10nT interval vertical and horizontal axis in degrees

squares method was then applied to separate the residual anomalies from the regional background field.

The method becomes handy and adequate because of the simple nature of the geology of the area and its limited spatial extent. We thus assumed reasonably that the regional field is a first-degree polynomial surface.

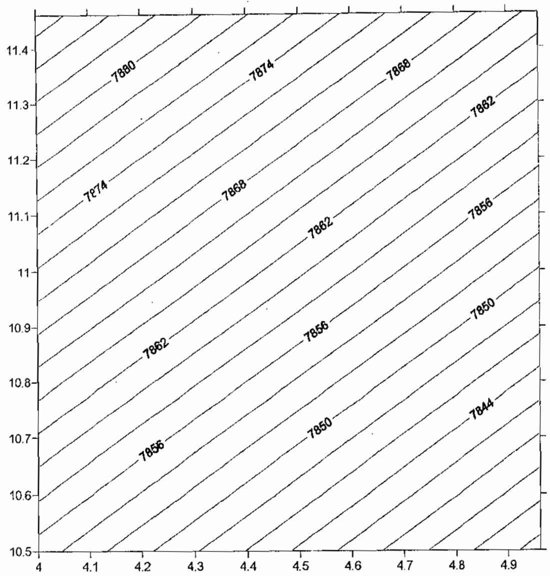

Fig.3: Regional Map of part of the lower Sokoto Basin

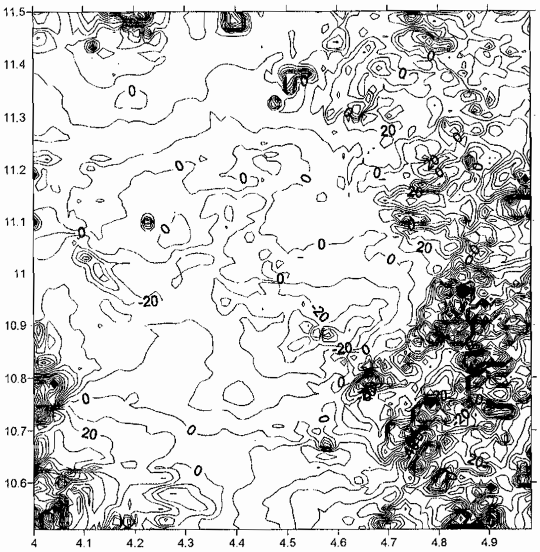

Fig. 4: residual magnetic anomaly map of the study area contoured at interval of 10nT

All the regional were therefore calculated as a two dimensional first-degree polynomial surface.

The value of the coefficients C_1, C_2 and C_3 calculated for the study area are as follows.

$C_1 = 7844.66$, $C_2 = -15.6155$ and $C_3 = -22.260$

The polynomial coefficients were used to compute the regional map of the study area. The resultant map is shown in Fig 3. The regional map trends NE-SW. The regional trend is attributed to effects, of deeper heterogeneity of the earth crust. The trend agrees completely with the deductions of Ajakaiye *et al.* (1980) who identified a system of NE-SW trending narrow magnetic lineaments along which are concentrated the Alkaline Ring complexes and suggested that the lineament represented pre-existing zones of weakness in the pan African crust. Anamba and Ajakaiye (1987) also identified predominant tectonic trends in the NE-SW and N-S directions over the present study area in particular and other parts of Northern Nigeria in general.

The residual magnetic values was obtained by subtracting values of the regional field from the total magnetic value at the grid cross points. The contour map of the residual value shown in Fig.4, which shows that the magnetic residual value ranges from 164.44nT to 117.44.nT.Negative residual dominate the study area because the area is close to the magnetic equator; this is in agreement with the view of Afleck (1963).

Spectral Analysis

The research area covering between longitude 40.0° and 5.0° and latitude 10.50° and 11.50° was sub-divided into forty-nine sections for the purpose of spectral depth determination, as shown on Table 1. Nine of these sections represent a square grid of 38 by 38 residual field points, which corresponds to a half degree by half-degree map i.e. 0. 5° by 0.5°; Each of these sections covered a total area of 55km by 55km. Sixteen (16) of the remaining section represents a square grid of 19 by 19 residual field points which corresponds to one-quarter degree

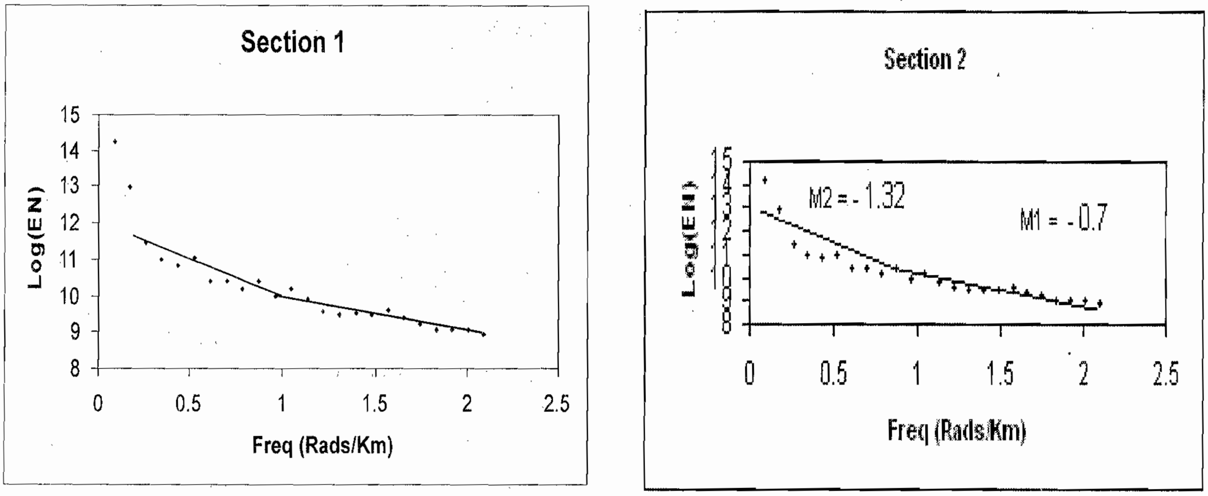

Fig 5: Energy spectra of section 1 and 2 with gradient values of 1st and 2nd linear segment as m1 and m2 respectively.

Table 1: Depth estimate and location for the 49 sections

SECTION	LONGITUDE	LATITUDE	H_1 (km)	H_2 (km)
1	4.25	11.25	0.52	0.89
2	4.75	11.25	0.37	0.66
3	4.25	10.75	0.38	1.29
4	4.75	10.75	0.30	1.86
5	4.50	11.25	0.25	0.66
6	4.50	10.75	0.41	1.40
7	4.25	11.00	0.40	1.1
8	4.75	11.00	0.43	0.97
9	4.5	11.00	0.228	1.57
10	4.125	11.375	0.38	0.57
11	4.375	11.375	0.45	0.665
12	4.625	11.375	0.26	1.96
13	4.875	11.375	0.60	1.15
14	4.125	11.125	0.73	1.5
15	4.375	11.125	0.346	1.35
16	4.625	11.125	0.40	1.3
17	4.875	11.125	0.50	1.40
18	4.125	10.875	0.77	1.9
19	4.375	10.875	0.54	1.83
20	4.625	10.875	0.22	1.43
21	4.875	10.875	0.67	1.20
22	4.125	10.625	0.62	1.87
23	4.375	10.625	0.46	1.66
24	4.625	10.625	0.96	1.81
25	4.875	10.625	0.34	1.56
26	4.25	11.375	0.50	1.43
27	4.50	11.375	0.44	1.77
28	4.75	11.375	0.55	1.39
29	4.25	11.125	0.71	1.56
30	4.50	11.125	0.715	1.54
31	4.75	11.125	0.57	1.55
32	4.25	10.875	0.42	1.80
33	4.50	10.875	0.43	1.25
34	4.75	10.875	0.31	0.96
35	4.25	10.625	0.43	1.73
36	4.50	10.625	0.5	1.73
37	4.75	10.625	0.46	1.66
38	4.125	11.25	0.5	1.93
39	4.375	11.25	0.25	1.84
40	4.625	11.25	0.43	1.47
41	4.875	11.25	0.65	1.36
42	4.125	11.00	0.12	1.66
43	4.375	11.00	0.23	1.3
44	4.625	11.00	0.59	1.89
45	4.875	11.00	0.47	1.51
46	4.125	10.75	0.37	1.56
47	4.375	10.75	0.15	1.79
48	4.625	10.75	0.48	1.09
49	4.875	10.75	0.48	1.66

by one-quarter degree i.e. 0.25° by 0.25° map. Each of these sections covered a total area of 22.5km by 22.5km. The remaining twenty four sections represents a rectangular grid of 19 by 38 residual filed points, which corresponds to half degree by one-quarter degrees i.e. 0.5° by 0.25° map. Each of these sections covered a total area of 22.5km by 55km.

This arrangement implies that spectral depth values are evaluated at every 0.125° by 0.125° of the map and this corresponds to approximately 15km by 15km interval.

Graphs of the logarithm of the spectral energies against frequencies obtained for the various sections are shown in Figure 5 Two best lines of fit drawn resulted into two linear segments. The first few points on the frequently axis of the graph was ignored because they represent frequencies of deeper sources, which could introduce errors. The gradient of each of the line segments were evaluated. Depth to basement are then evaluated using equation (15) i.e. $Z = -M/2$ where M represents the gradient and Z gives the mean depth of buried assemblage. These depths were shown as H2 on table (1), from the table, the first layer depth varies in thickness from 0.22km minimum to 0.96km maximum, and has an average thickness of 0.457km. The second layer (H2) depth varies from a thickness of 0.46km minimum to 1.96km maximum and has an average depth of 1.45km.

Discussions and conclusion

The result of the spectral analysis of the aeromagnetic data over part of the lower Sokoto Basin identified two main magnetic horizons under the area, the low frequency segments of the spectral graph represent the deeper sources, and the high frequency segment represents the shallower magnetic sources.

The value of H_2 obtained Table 1 was used to produced the contour map of the second layers spectral depth, Fig. 6 and the surface plot for the second layer depth Fig. 7 which are used for interpretations.

The first layers, which are of shallower

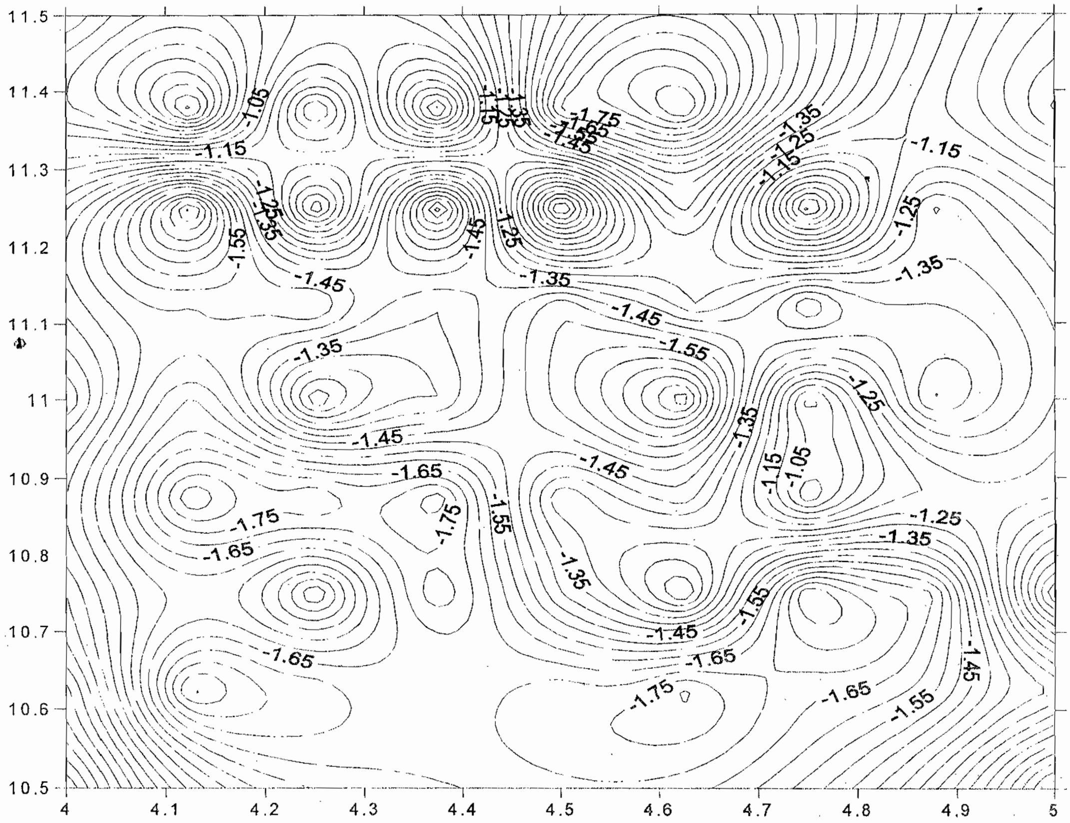

Fig 6:.Contoure map of the second layer depth contoured at an interval of 50 meters.

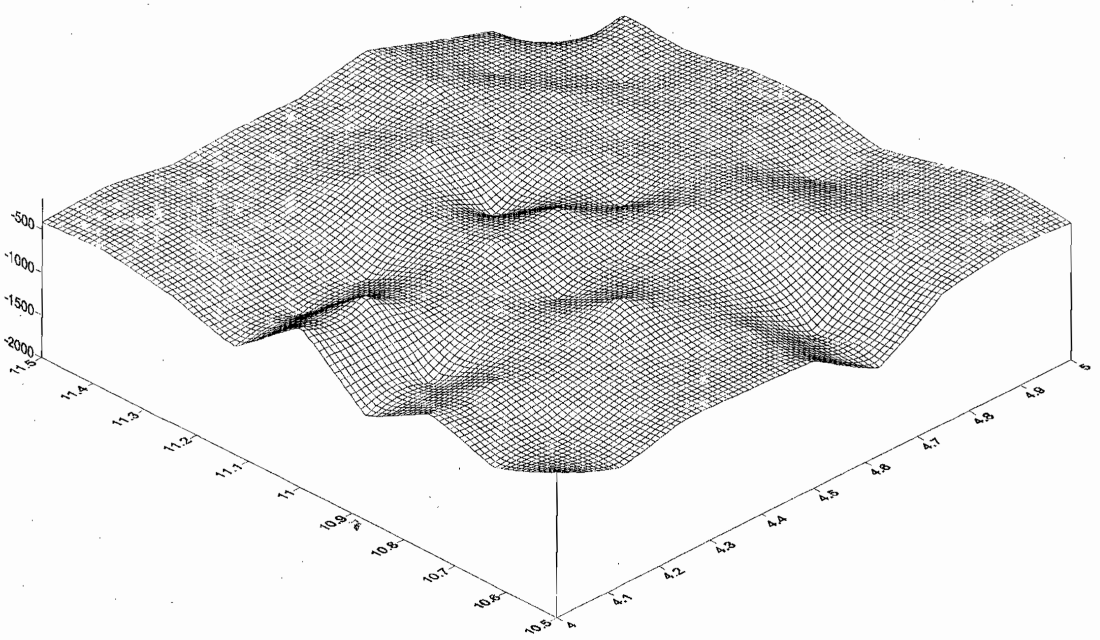

Fig. 7: Surface plot of the second layer depth contoured at interval of 100meters

magnetic sources brought out by the above analysis, can be attributed mostly to lateritic ironstone capping and the effect of surrounding basement magnetic rocks. The second layer which are of deeper sources may be attributed to magnetic rocks intrude onto the basement surface. Another probable origin of the magnetic anomalies contributing to this layer are lateral variations in basement susceptibilities and intrabasement features like faults and fractures (Kogbe, 1981) . In either case we can reasonably deduce that the H2 values obtained from the above spectral analysis represents the average depth of the basement complex in the section considered.

The result of the spectral analysis of aeromagnetic data over the basin suggests the existence of two main source depths. The deeper source depth lie at a depth that varies between 0.46km and 1.93km. These deeper sources that are represented by low frequency component of the spectrum are considered to reflect the depth to the magnetic basement.

A generalized depth to magnetic basement map produced from the depth results of the spectral analysis over the study area, reveals a shallow basement surface, which averages to 1.44km.

A comparison of the basement depth estimate of this work with the results obtained by Umego (1990) using Werner Deconvolution methods shows that Umego (1990) analysis gave basement depth of between 1.2km and 2.0km while the present study estimated the basement of between 0.46km and 1.93km shows that the result is in agreements with Umego (1990) predicted depths. Hence the following conclusions can be arrived at.

1. The result from this spectral analysis has revealed that the basin is generally shallow, with an average of 1.44km of thickness for sediments in the lower Sokoto Basin. One important significance of this result is in consideration of hydrocarbon accumulation potential of the basin, if all other conditions for hydrocarbon accumulation are favourable, and the average temperature gradien 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 would be 2.3km. .

(Wright *et al.,* 1985) The result obtained fall short of this expectation. This indicates that the prospect for hydrocarbon accumulation is not promising

2. The predicted depth by Umego (1990) using Werner deconvolution looks more acceptable to the researcher compared to that from gravity method were a lower value of 1.0km was obtained as the maximum thickness.

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