GLOBAL JOURNAL OF GEOLOGICAL SCIENCES VOL 1, NO. 2, 2003: 129 - 142
 ISSN 1596-6798

SPECTRAL ANALYSIS AND HILBERT TRANSFORM OF AEROMAGNETIC DATA OVER THE UPPER BENUE TROUGH, NIGERIA.

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(Received 17 April 2002; Revision accepted 14 November 2002).

ABSTRACT

Two-dimensional spectral analysis and Hilbert transformation of aeromagnetic data over the Upper Benue trough were carried out in order to estimate the depths to magnetic sources and also delineate the major structural patterns in the study area. The analysis conducted indicates a two-depth source model. The deeper magnetic sources depth of up to 3328 m was obtained, representing the sedimentary cover in the study area. The highest depth to the shallower magnetic source model is 830 m and represents intrusive/extrusive bodies within the trough. The results presented here are important in understanding the structural and tectonic evolution and the preliminary assessment of the hydrocarbon generation and maturation prospects of the Upper Benue Trough.

Keywords: Upper Benue trough, Fourier Transform, Hilbert Transform, sediment thickness and Crustal Structure

INTRODUCTION

The Benue Trough is a linear northeast-southwest trending rift system whose development was closely associated with the split of Africa from South America and the opening of the South Atlantic Ocean in the Cretaceous. The origin and evolution of the Benue Trough are now fairly well documented (Nwachukwu, 1972; Olade, 1975; Benkhelil, 1988). The Trough is characterized by the occurrence of several minerals of economic importance, namely; coal, barytes, lead and zinc just to name a few.

The present study is concerned with the interpretation of the aeromagnetic data over the Upper Benue Trough. The total area studied spans a territory of 256 km by 256 km, extending from latitude 9° 00' N to 11°16' N and longitude 10° 00'E to 12°16'E. The area houses a thick sedimentary rock sequence comprising sandstones, clays, siltstones, limestones and shales. There are also basalts and trachytes as well as exposures of the crystalline Basement Complex rocks bordering the Trough (Fig. 1).

The petroleum potentials of the Upper Benue Trough is a matter of great interest, and the determination of sediment thickness above the basement and the delineation of major geological structures represent an essential step towards the assessment of the petroleum potential of this area. With the help of two-dimensional spectral analysis and two-dimensional Hilbert transform the variation of the basement depths and fracture zones have been determined. The results in this work would also be a contribution to a better understanding of the Upper Benue trough.

GEOLOGY OF THE AREA

The geology of the Upper Benue Trough has been described in some details by Carter et. al. (1963). The oldest sedimentary rocks belong to the Bima Sandstone whose lower beds are more feldspathic than the higher

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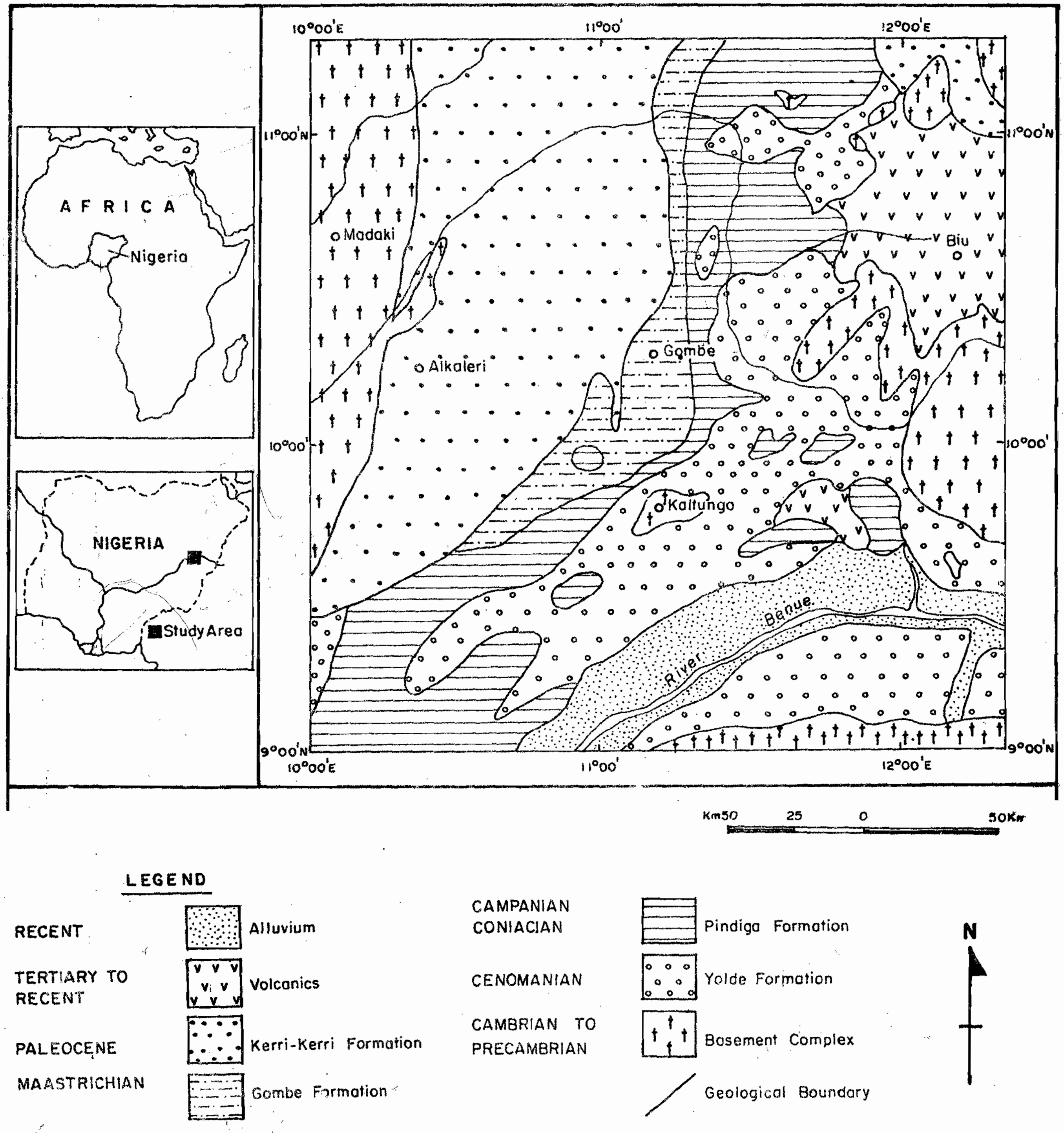

Fig. 1: Geological map of the Upper Benue Trough, Nigeria
(After Geological Survey of Nigeria, 1984)

beds. The age of the formation ranges from Upper Albian to Turonian. The Yolde and Pindiga Formations (Fig.1) are also present in the area of study. The Yolde Formation is a variable sequence of sandstones and shales, which mark the transition from continental to marine sedimentation. The formation contains ammonites of Lower Turonian age. The Pindiga Formation is a sequence of marine shales with a number of limestone beds towards the base of the formation. The upper part of the formation consists of blue-black shales. The formation is dated from Lower Turonian to Maastrichtian. The stratigraphic sequence of the Benue Trough and Chad Basin (Nwajide, 1990) is shown in Table 1.

The Gombe and Kerri-Kerri Formations are also present and represent the Upper Maastrichtian to Paleocene sediments in the Upper Benue Trough. The Gombe Formation is a sequence of estuarine and deltaic sandstone

	Age	Southern Benue Trough	Middle Benue Trough	Northern Benue Trough
	Eocene	Ameki Fm / Nanka Fm / Nsugbe Ss	Volcanics	Volcanics
54.9	Paleocene	Imo Formation	Keri - Keri Formation	Keri - Keri Formation
65	Maastrichtian	Nsukka Formation Ajali Sandstone Mamu Formation	Volcanics Lafia Formation	Volcanics Gombe Sandstone
73	Campanian	Owelli Sandstone / Otobi Sandstone → Enugu Formation / Mkporo Formation		Lamja Ss / Gongila Fm / Fika Shale
83	Santonian	Agbani Sandstone / Awgu Formation →		Numanha Fm / Gulari Ss
87.5	Coniacian			Sekule Formation
88.5	Turonian	Shale Units Agala Ss / Igumale Lst Amaseri Sandstone Nkalagu Limestone Shale Units Ogoja Sandstone	Makurdi Fm (incl. Wadata Lst) Yurak Formation Keana Sandstone	Jessu Formation Dukul Fm / Gongila Fm
93	Cenomanian	Odukpani Formation Awi Formation	Awe and Uomba Fms / Kuabai Fm / Yolde Formation Arufu Limestone Yandev Limestone / Muri Ss / Bima Sandstone	
100	Albian	Okposi Formation Unnamed units Abakaliki Shale		
119 my	Aptian Barremian Hauterivian	Unnamed units	Pre-Bima Sandstone	
	Precambrian - Cambrian	Basement Complex		

Table 1. Summary of Early Cretaceous to Early Tertiary deposits in the Benue Trough (After Nwajide, 1990)

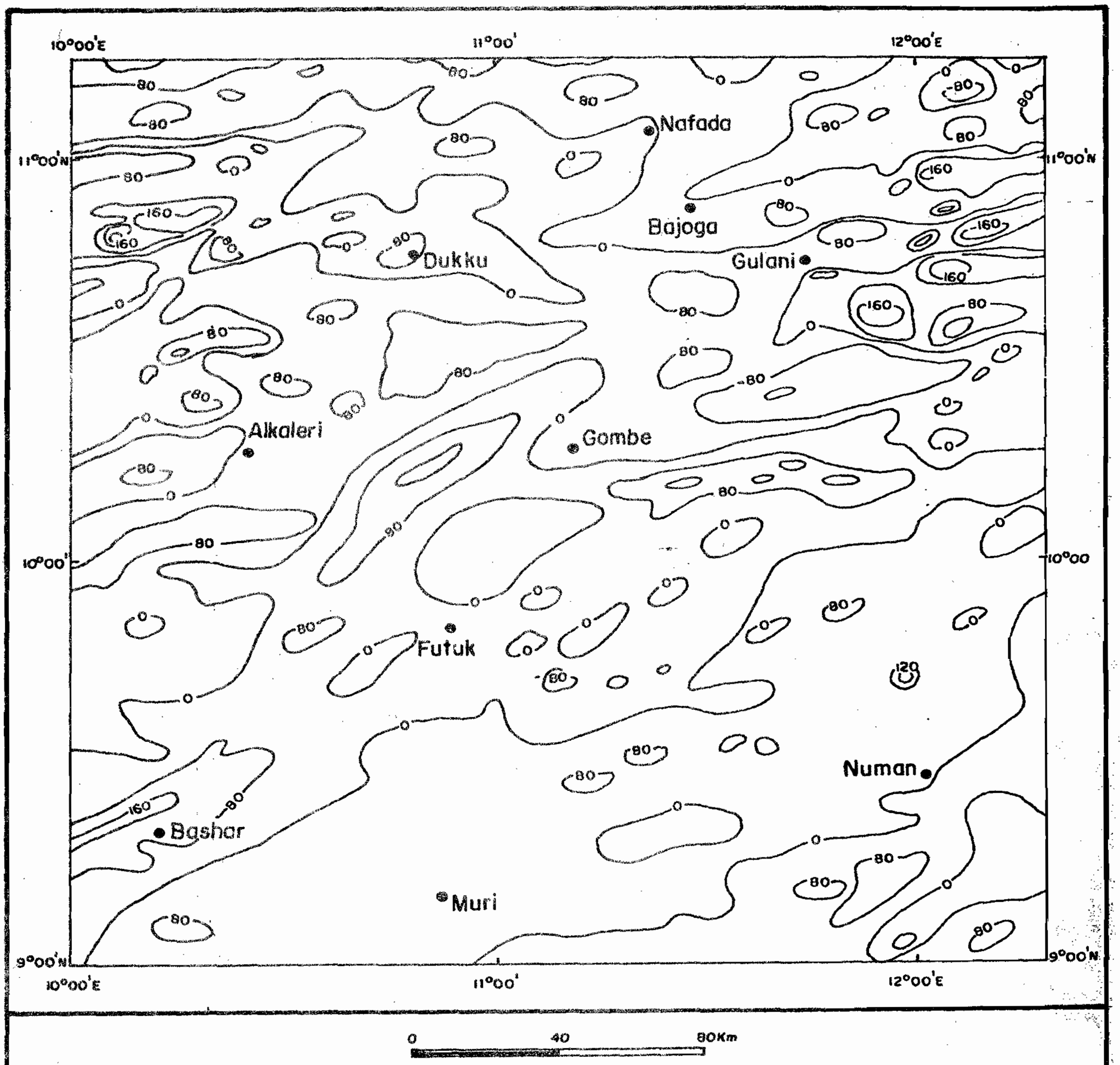

Fig. 2: Residual magnetic field over the Upper Benue Trough as contoured map (Contour Interval = 80 nT)

siltstone, shale and ironstone. The Kerri-Kerri Formation is a continental sequence, which was deposited under a wide range of conditions.

The Biu Basalts of Tertiary age are mainly basalt and trachyte and the Basement Complex is also present in the study area (Fig. 1). The basement rocks are of Precambrian age and consist mainly quartz-feldspathic and biotite, hornblende-gneisses, marbles, and calc-silicate rocks.

ANALYSIS OF THE AEROMAGNETIC DATA

Spectral analysis.

Two-dimensional techniques of spectral analysis for magnetic data analysis has been described by several authors (Bhattacharyya, 1966; Naidu, 1969; Spector and Grant, 1970; Negi, et al., 1983; Ofoegbu and Onuoha, 1991, Nur et al., 1994; Nur, 2000 etc.). In the present paper, we utilized the approach of Nur, (2001) to analyze the data over the Upper Benue trough. Given a residual magnetic map of dimensions L x L digitized at equal intervals, the total residual magnetic anomaly values can be expressed in terms of a double Fourier series expansion.

$$T(x, y) = \sum_{n=1}^{L} \sum_{m=1}^{L} P^n_m \cos[(2\pi/L)(nx+my)] + Q^n_m \sin[(2\pi/L)(nx+my)] \quad \ldots \quad (1)$$

where L = length of the square side,

P^n_m and Q^n_m = Fourier Amplitudes and n,m = number of grid points along the x,y directions, respectively.

The sum

$P^n_m \cos[(2\pi/L)(nx+my) + Q^n_m \sin[(2\pi/L)(nx+my)]$ represents a single partial wave for which

$$(P^n_m)^2 + (Q^n_m)^2 = (C^n_m)^2 \quad \ldots\ldots\ldots\ldots \quad (2)$$

C^n_m is the amplitude spectrum of the partial wave while the frequency spectrum of this wave is given as

$$f^n_m = (n^2 + m^2)^{1/2} \quad \ldots\ldots\ldots\ldots \quad (3)$$

The Fourier transform of a section of some magnetic maps digitized in some square grid therefore form a rectangular matrix of coefficients, which can be reduced to a set of average amplitudes dependent only on the frequency (Hahn et al.1976). The average amplitudes fully represent a spectrum for which the depth to magnetic sources can be estimated.

The average amplitude spectrum of all waves falling within a given frequency range is then computed by summing the Fourier amplitudes and dividing the sum of the number of frequencies. These average amplitudes are then plotted against the frequency on a semi-log scale. According to Negi et al.(1983) the depths (z) to the magnetic sources are related to the slopes of the line segments thus:

$$Z = SD/2\pi \quad \ldots\ldots\ldots\ldots \quad (4)$$

where S= slope; D = length of a square side of the block.

The aeromagnetic data for this work was originally acquired by the Geological Survey of Nigeria along a series of E-W profiles with a spacing of 2 km, and a nominal tie-line spacing of 20 km. The geomagnetic gradient was removed from the data using the International Geomagnetic Reference Field (IGRF) formula of first January 1974. Sixteen complete magnetic map sheets and, parts of nine others were utilized for this work. The digitization was at 2 km intervals. To eliminate the regional field, a plane surface has been fitted to the data by multi-regression least-squares analysis, and the expression for the regional obtained was: -

$$T(x, y) = 7812.871 + 0.674x + 0.114y \ldots \quad (5)$$

where x and y are units of spacing of the digitized magnetic data.

The regional field values were subtracted from the observed data, and the obtained residual field over the study area is shown in Figure 2. In order to carry out the spectral analysis, the residual data Figure 3 was divided into sixty-four blocks containing 16 x 16 data points. Using the above formulae a Fortran programme, the average depths of the sixty-four blocks making up the area of study were computed (Table 1). Figures 3 shows typical example of spectra of

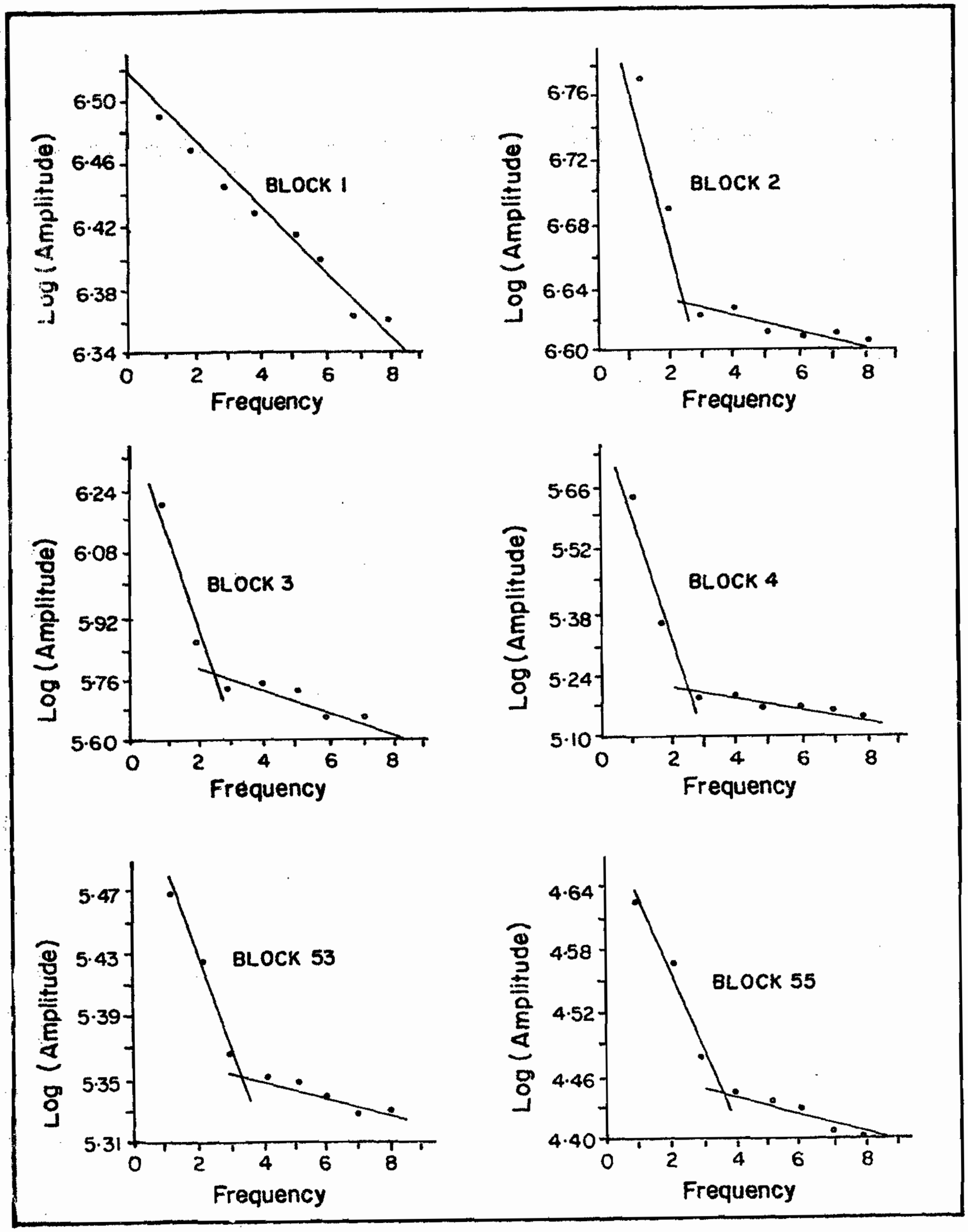

Fig. 3: Some examples of amplitude spectra in the area of study

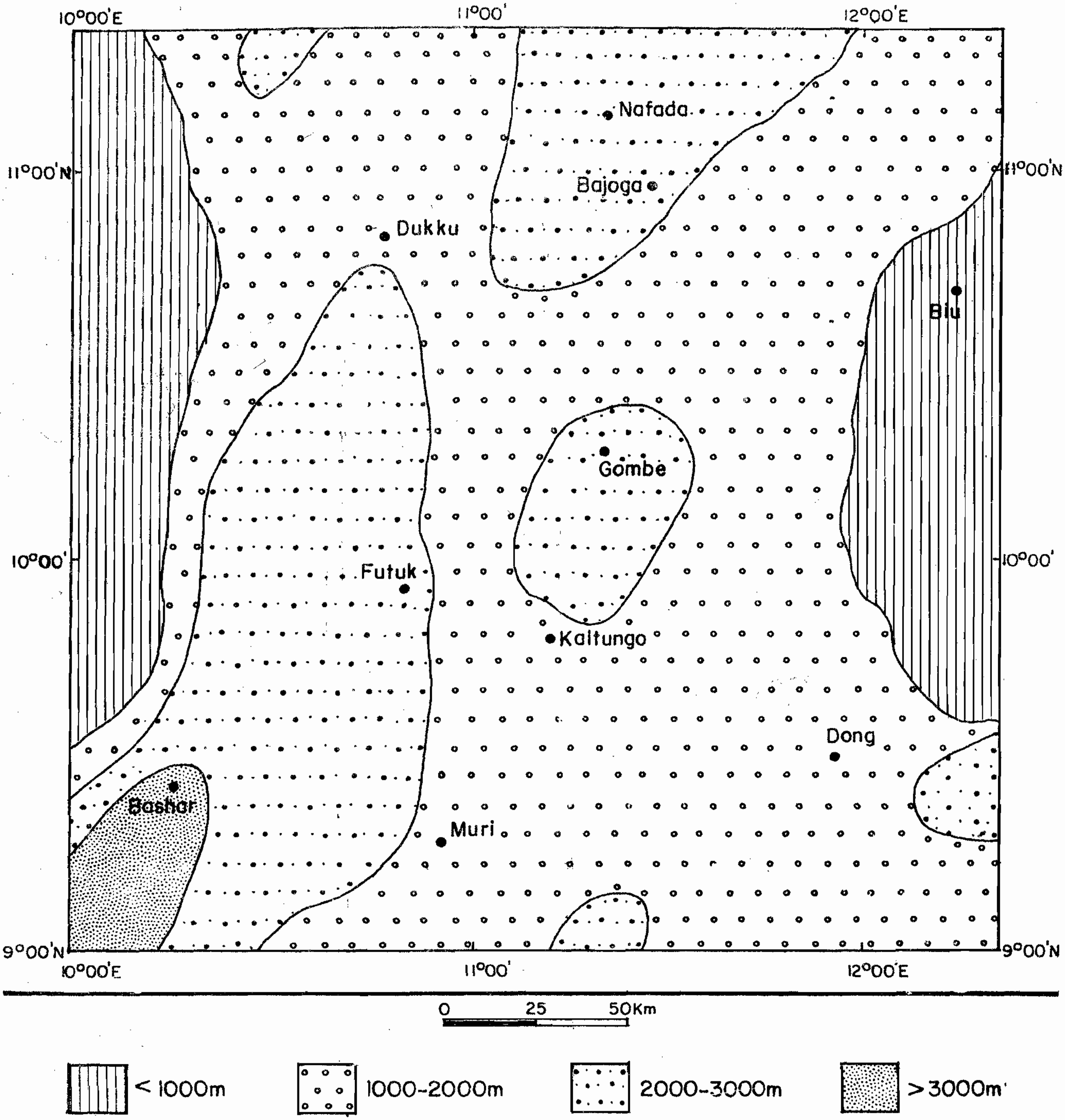

Fig: 4: Sediment thickness deduced from the spectral analysis of magnetic data over the Upper Benue Trough

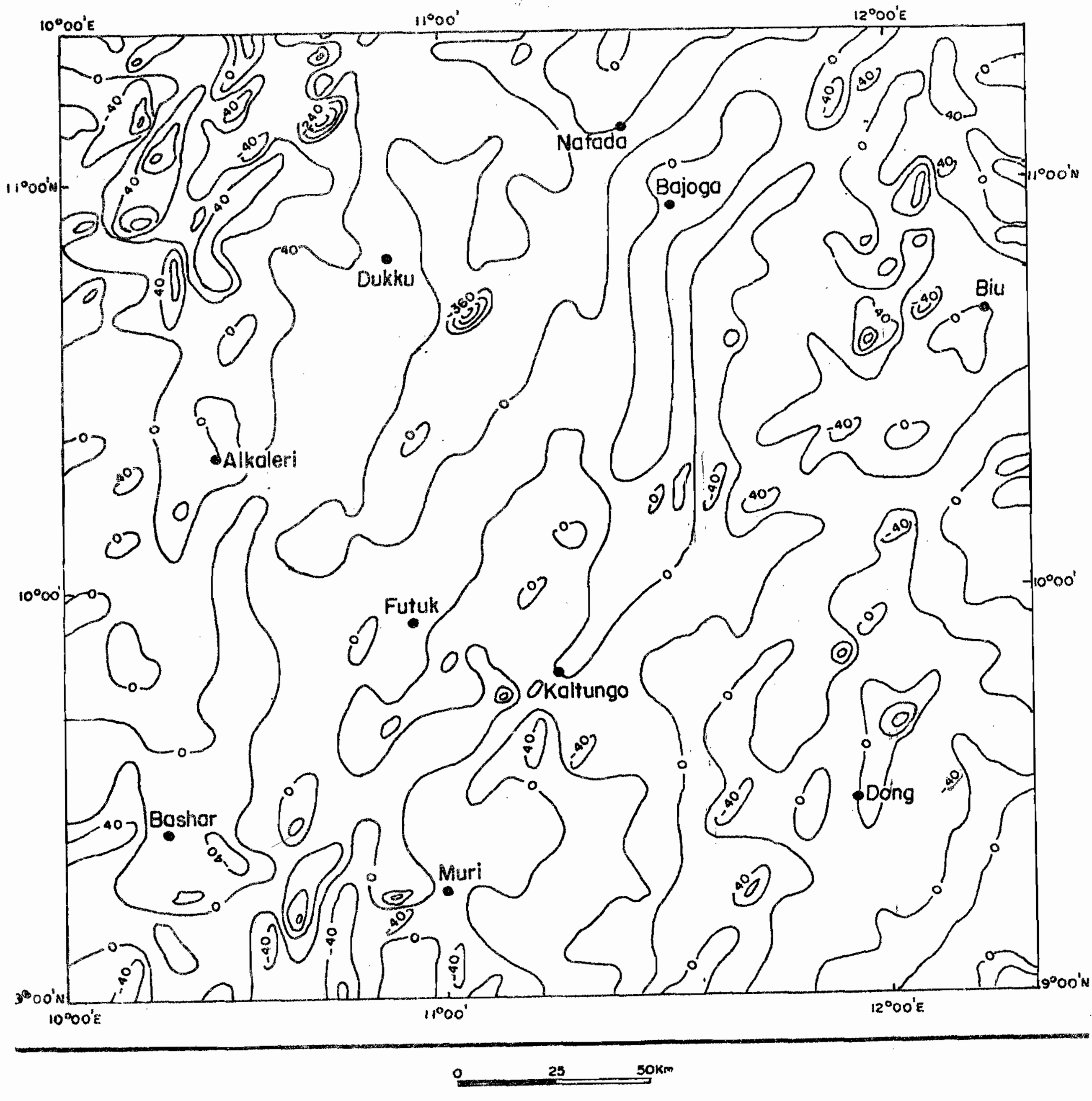

Fig. 5: Contour map of horizontal derivatives
(Contour Interval 40 nT/Km)

some blocks in the study area. The first segment with low frequency represents the deep magnetic source bodies, while the second segment with high frequency represent shallow magnetic source bodies. The deeper magnetic source bodies constituting 87.5 % of the study area was contoured and shown in Figure 4. This is very important in understanding the variation of sediment thickness across the study area.

Hilbert transform.

Hilbert transformation has been shown to be useful for transformation of magnetic anomalies (Shuey, 1972; Nabighian, 1972; Ram Babu et al., 1989 and Ofoegbu and Mohan 1990, Nur, 2001). Nabighian (1972) applied two-dimensional Hilbert transformation to compute the vertical derivatives of magnetic field from horizontal derivatives and

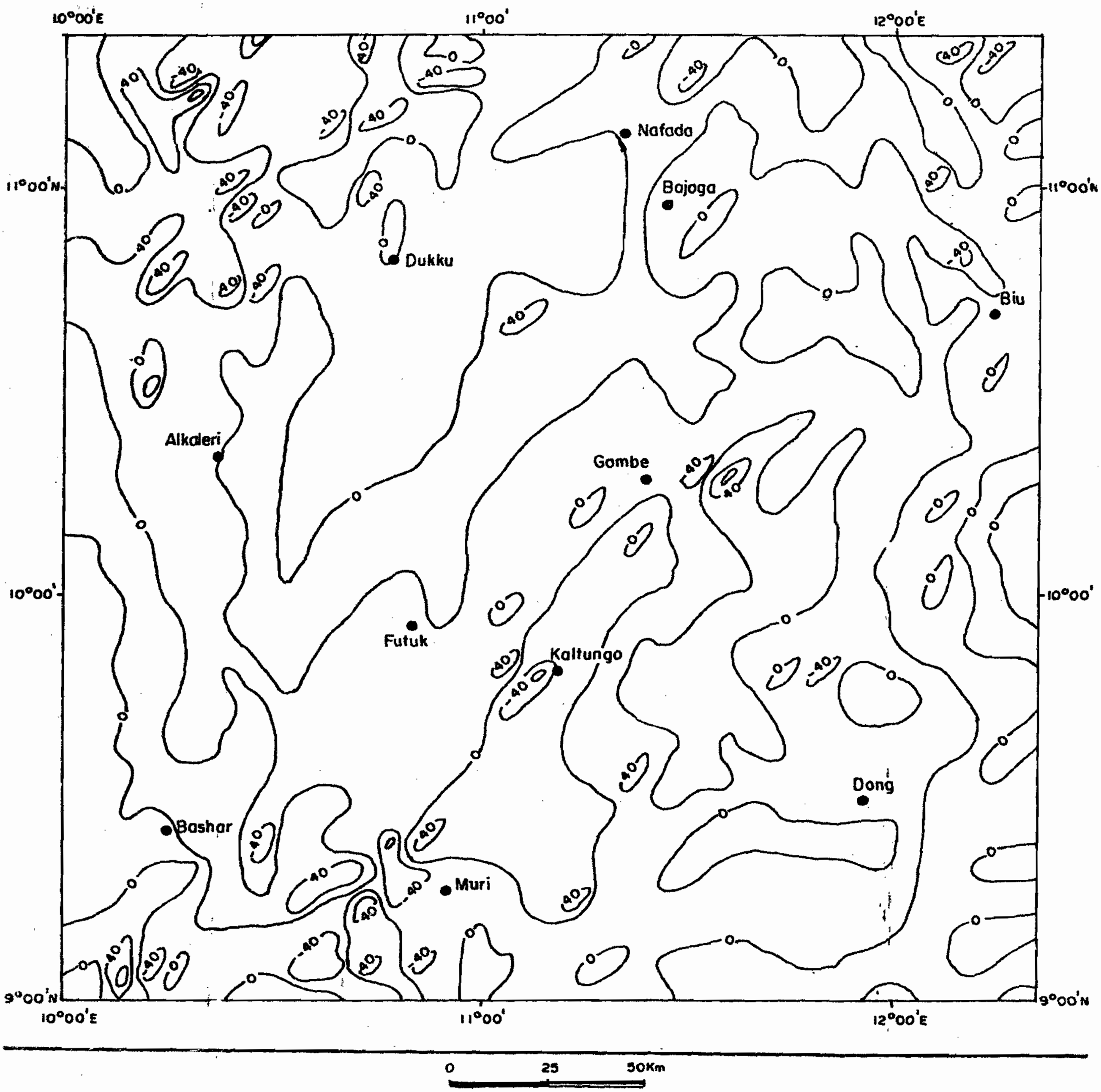

Fig. 6: Contour map of Hilbert transform (Contour Interval = 40nT)

Table 2. Magnetic source depths obtained from the spectral analysis in the Upper Benue Trough, Nigeria (All Depths D1 and D2 are in km)

Block 1 D1=0.395	Block 2 D1=2.094 D2=0.517	Block 3 D1=1.905 D2=0.590	Block 4 D1=1.406 D2=0.530	Block 5 D1=2.024 D2=0.502	Block 6 D1=2.616 D2=0.502	Block 7 D1=2.027 D2=0.572	Block 8 D1=1.269 D2=0.477
Block 9 D1=0.413	Block 10 D1=1.728 D2=0.525	Block 11 D1=1.910 D2=0.566	Block 12 D1=1.479 D2=0.555	Block 13 D1=2.320 D2=0.566	Block 14 D1=1.773 D2=0.530	Block 15 D1=1.375 D2=0.555	Block 16 D1=1.169 D2=0.459
Block 17 D1=0.391	Block 18 D1=1.452 D2=0.663	Block 19 D1=2.729 D2=0.586	Block 20 D1=1.753 D2=0.541	Block 21 D1=1.829 D2=0.574	Block 22 D1=1.054 D2=0.784	Block 23 D1=1.528 D2=0.497	Block 24 D1=0.373
Block 25 D1=0.388	Block 26 D1=2.095 D2=0.524	Block 27 D1=2.865 D2=0.533	Block 28 D1=1.868 D2=0.830	Block 29 D1=2.491 D2=0.487	Block 30 D1=1.309 D2=0.563	Block 31 D1=1.183 D2=0.563	Block 32 D1=0.355
Block 33 D1=0.355	Block 34 D1=2.891 D2=0.487	Block 35 D1=2.590 D2=0.701	Block 36 D1=1.524 D2=0.530	Block 37 D1=2.913 D2=0.522	Block 38 D1=1.900 D2=0.546	Block 39 D1=2.622 D2=0.552	Block 40 D1=0.463
Block 41 D1=0.997 D2=0.478	Block 42 D1=2.702 D2=0.563	Block 43 D1=2.660 D2=0.541	Block 44 D1=1.951 D2=0.530	Block 45 D1=2.224 D2=0.477	Block 46 D1=1.972 D2=0.512	Block 47 D1=0.678 D2=0.647	Block 48 D1=1.269 D2=0.592
Block 49 D1=3.195 D2=0.469	Block 50 D1=2.847 D2=0.540	Block 51 D1=2.202 D2=0.541	Block 52 D1=1.603 D2=0.530	Block 53 D1=1.450 D2=0.521	Block 54 D1=1.540 D2=0.489	Block 55 D1=1.232 D2=0.535	Block 56 D1=2.347 D2=0.542
Block 57 D1=3.328 D2=0.477	Block 58 D1=1.830 D2=0.530	Block 59 D1=1.555 D2=0.530	Block 60 D1=1.448 D2=0.569	Block 61 D1=2.648 D2=0.497	Block 62 D1=1.771 D2=0.568	Block 63 D1=1.676 D2=0.580	Block 64 D1=1.555 D2=0.541

vice versa. Ofoegbu and Mohan (1990) presented a more simplified mathematical expression of 3-D Hilbert transformation for observed magnetic field anomalies. The present work uses two-dimensional Hilbert transform whose mathematical expression is of the form:

$$f'(x) = 1/\pi \int [f(x')/(x'- x)]\, dx \quad \ldots\ldots\ldots\ldots \quad (6)$$

Applying this to magnetic anomalies, the Hilbert transform of the first vertical and horizontal derivatives ($T_z(x')$, $T_x(x)$) of the total magnetic field anomaly ($T(x)$) are of the form:

$$T_z(x') = 1/\pi \int Tx(x)/(x-x')dx$$

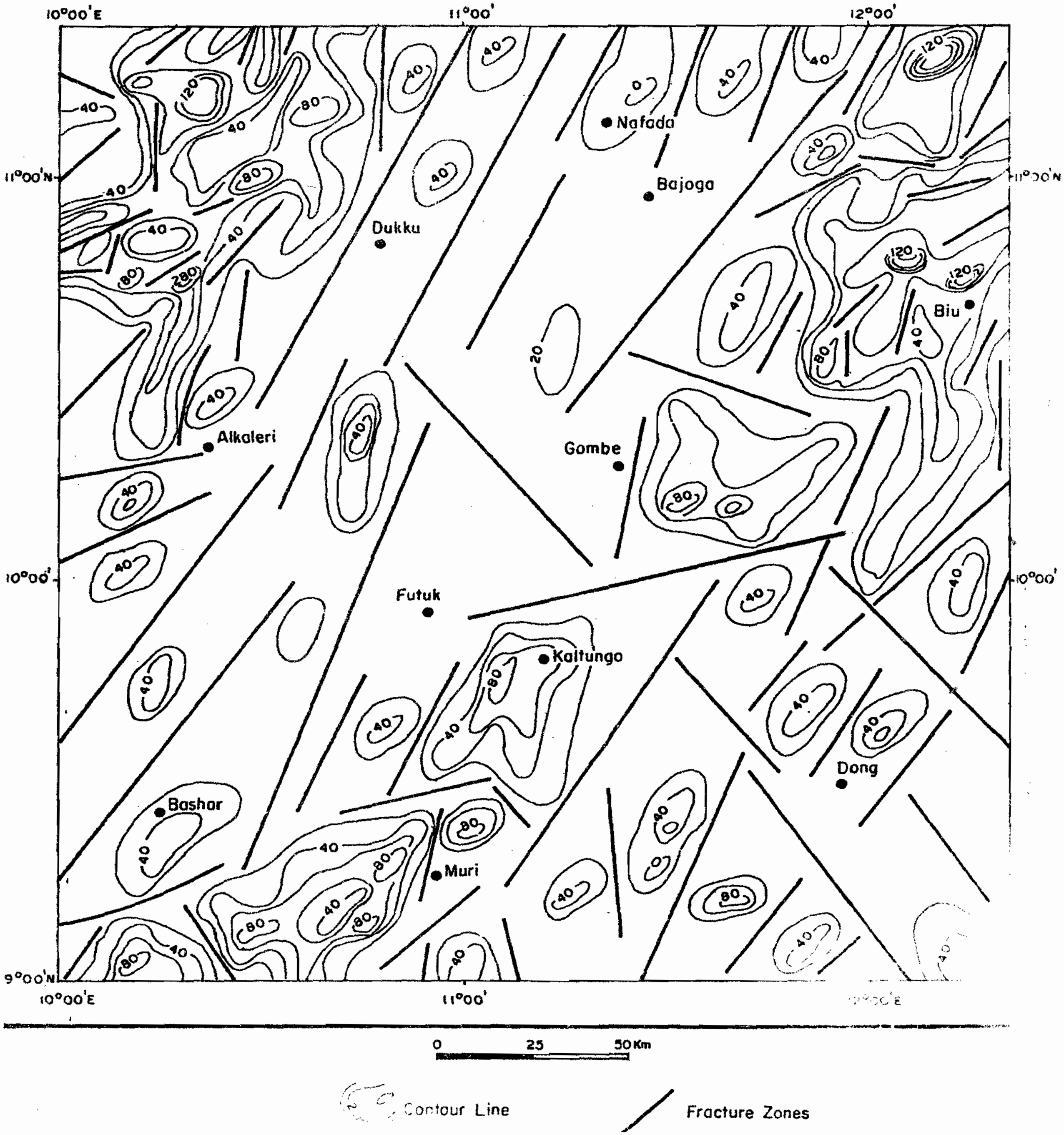

Fig. 7: Contour map of amplitude or analytic signal (Contour Interval = 20 nT)

$T_x(x) = -1/\pi \int Tz(x')/(x-x')dx'$ .... (7)

The vertical and horizontal derivatives are Hilbert transform pairs. The analytical signal or the amplitude is expressed as

$A(x)=[T_x^2+T_z^2]^{1/2}$ .... (8)

The residual magnetic data were used as input into a 2-D Hilbert transform program and the resultant values are shown in Figures 5 and 6. The analytic signal is very important in the delineation of the structural patterns of the study area Figure 7.

DISCUSSION OF THE RESULTS

Magnetic source depth determinations through spectral analysis over the Upper Benue Trough area suggest that 87.5 % two source depths and 12.5 % of single source depth under the area as shown in Table 2 and typical example of some blocks in Figure 3.

From the deeper magnetic source depth, there are sub-basins identified within the upper Benue trough (Fig.4). These are as follows: -

a) The Bashar-Futuk area:- the average magnetic source depth obtained varies between 2202 m and 3328 m. This represents the largest and the thickest sub-basin within the Upper Benue Trough, and may probably extend southwest outside of the present study area.

b) The Nafada-Bajoga area:- the average magnetic source depths obtained vary between 2024 m and 2616 m. Thissub-basin may also have an extension towards northeast outside of the study area.

c) Gombe area:- the average magnetic depth is 2913 m deep and, the area extent of this sub-basin is over 55 km^2.

d) Other three smaller sub-basins that are deep (over 2000 meters) are also found in the north, south and east of the area of study as shown on Figure 4.

A comparison of the sediment thickness in the study area with those previously estimated from gravity and magnetic analysis shows a good general agreement. For example, Osazuwa et al. (1981) obtained sediment thicknesses that range from 0.9 km to 2.2 km from gravity data interpretation, and 0.9 km to 4.9 km from magnetic data interpretation. Ofoegbu (1988) from magnetic data interpretation obtained sediment thickness that range from about 0.5 km to about 4.6 km for the Upper Benue Trough.

The results obtained from the Hilbert transformation are presented as contoured maps (Figs.5 and 6). These contour maps compare well with the residual magnetic map on Figure 2, which is the reflection of the Geology of the area. There are noticeable NE-SW, NW-SW, N-S and E-W striking features on the analytic signal contour map (Figure 7). These features may be interpreted as fracture zones, which originally developed in the zones of weakness within the trough. From the results of spectral analysis (Table 2 and Figure 4) these features could be considered a deep sub-basins hosting sediments containing very low ferri-magnetic elements. The thick sediments existing in the sub-basins (Figure 4) and the fracture zones on the analytic signal map (Figure 7) gives an encouraging start for more serious and detailed geophysical investigations for hydrocarbons in the Upper Benue Trough.

The results obtained from the spectral analysis and the Hilbert transformation could be explained best in terms of intrusive igneous bodies of variable depths existing beneath the Benue Trough. The variable basement depth can be closed be related to the tectonic and structural evolution of the trough. The evolution of the trough is thought to have involved the rise of a mantel plume that gave rise to up doming and development of initial lines of weakness marginal to the plume (Burke and Dewey, 1973 and Ofoegbu 1984). The mantle plume activities in the initiation of the thinning and rifting in the Benue Trough, manifested in the lateral and vertical variations of the Curie isotherm surface across the trough. There were also the emplacement of intrusive/extrusive rocks along the lines of weakness, thick sedimentation, folding and block faulting. The crustal thickness and the depth to the Moho of some parts of the trough were found to coincide each other (Nur et al. 1999).

CONCLUSION

Basement depths have been determined for the Upper Benue Trough from spectral analysis of aeromagnetic data over the area. Sediment thickness vary across the area, with the thickest sediment cover found in the southwestern portion of the study area, around Bashar-Futuk, where the basement is situated below 3300 m. of sediments. The thick sediments have been deposited as the result of the tectonic instability and gradual subsidence together with faulting and folding occurred and manifested the presence of the irregular nature of the floor of the Upper Benue Trough with sub-basins being separated by horst-like features. Based on the Hilbert transformation there exist lineaments of NE-SW, NW-SW, N-S and E-W trending feature. The results of the present work are in agreement with results from previous geological and geophysical study in the area. From the point of view of sediment thickness and the structural pattern, the sub-basin in the southwest of the study area may provide good prospects for hydrocarbon exploration in future. The current exploration activities including the acquisition of seismic data over specifically selected regional lines are therefore justified.

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