INTERNATIONAL JOURNAL OF NATURAL AND APPLIED SCIENCES (IJNAS), VOL. 3, NOS.1& 2 (2008); P. 69 – 74, 1 TABLE, 8 FIGS.

Mapping depth to the crystalline basement in the Lower Benue trough (Nigeria) using power spectrum and horizontal gradient magnitude techniques on aeromagnetic data.

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ABSTRACT

Mapping magnetic basement is an important tool in oil and gas exploration. Aeromagnetic data can define the basement over a large basin area because of the significant magnetic contrast between the crystalline basement rocks and the relatively non magnetic sedimentary cover rocks. Nine Aeromagnetic maps on a scale 1:100,000, covering the Lower Benue Trough, were digitized and processed using computer techniques, including reduction – to – the - pole, polynomial filtering and power spectrum and horizontal gradient magnitude techniques (HGM) approaches for depth estimations. The results indicate sediment thickness of less than 2.5 km and 2.5 to 5.0 km in the Afikpo and Uwet (calabar flank) sub-basins based respectively on the power spectrum and HGM approaches. However, comparison with available well information for the calabar flank indicated that the HGM – derived depth estimates were of better accuracy. In addition, the lateral extents of the sub-basins appeared to have been better outlined by the HGM- derived depth estimates.

INTRODUCTION

The area of study is delimited by latitudes $5^0.00'$ and $6^0.30'$ N and longitude $7^0.00'$ and $8^0.30'$E in southeastern Nigeria. It is part of the Lower Benue trough (Fig.1) which includes the Abakiliki anticlinorium, and its flanking depression (Anambra basin and Afikpo syncline), and the Calabar Flank as major structural elements. The Benue Trough extends for some 1,000km northeastward from the coastline and overlies Precambrian basement rocks (gneisses, migmatites, granites, etc) (Fig.1). It is believed to have formed in Cretaceous time as a result of the breakup between the South American and African continents and is considered as an arm of the triple junction situated at the location of the Niger delta on the southwestern end of the trough (Fairhead and Okereke,1987) .

The sedimentary fill in the Benue trough comprise mostly shales, sandstones, and limestones which were deposited by several marine transgressions and regressions (Petters and Ekweozor, 1982). The strata range in age from Albian to Eocene with an overall thickness extent of up to 5,000 m. In late Santonian time the trough experienced a major deformational episode which caused folding, faulting and igneous activity. The main products of this deformation include the Abakaliki fold belt with its associated lead-zinc mineralisation and the new depocentres of the Anambra and Afikpo depressions.

Fig. 2 shows the major rock units in the study area. The oldest sediments belong to the Asu River Group (Albian) which unconformably overlies the basement and is overlain by the Eze Aku Shales (Cenomanian to Turonian) and the Awgu Shales Formation (Turonian to Santonian). The Nkporo Shales (Campanian to Maastrichtian) and the regressive sequence of the Coal measures (Maastrichtian) mark the start of the post-deformational cycle.

A few wells have penetrated the basement in the study area and indirect estimates of depths to the basement, from geophysical studies, are generally lacking. The sediment thickness distribution is therefore not well known. Since such information is useful for assessing the hydrocarbon exploration potential of frontier basins, the present study was carried out to determine depths to the magneti basement in the study area utilizing the power spectrum and the horizontal gradient magnitude methods. Ofoegbu and Onuoha (1991) and Nur et al. (2003) have applied the power spectrum method od determining depth to the magnetic basement in other parts of the Benue trough while Benkhelil et al.(1989) have reported on similar depth determinations for the entire trough using the (graphical) half – slope method and an assumed horizontal regional anomaly.

THEORETICAL BACKGROUND

Power spectrum

The 2D spectral analysis of magnetic anomalies has been described by Ofoegbu and Onuoha (1991), Ferdi et al. (1997), Spector and Grant (1985), and Hahn et al. (1976). Thus, given a residual magnetic anomaly map of dimensions L x L digitized at equally spaced intervals, the residual total intensity anomaly values, T(x, y), can be expressed in terms of a double fourier series expansion:

$$T(x,y) = \sum \sum P_m^n \cos (2\pi/L) (nx + my) + Q_m^n \sin(2\pi/L) (nx + my) \qquad (1)$$

where L= length of the square side, P_m^n and Q_m^n = Fourier amplitude and n and m = number of grid point along the x- and y- directions.

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So, the Fourier transform of a section of a magnetic survey digitized in a square grid forms a rectangular matrix of coefficient which can be reduced to a set of average amplitudes dependent on the frequency. These average amplitudes can be estimated.

Horizontal gradient magnitude

The horizontal gradient magnitude method is a simple approach to estimating contact locations and depths (Philip, 1997). If m(x,y) is the magnetic field, and $\frac{dm}{dx}$ and $\frac{dm}{dy}$ are its derivatives in the x- and y-directions then the horizontal gradient magnitude HGM(x,y) is given by:

$$\text{HGM}(x,y) = \sqrt{\left(\frac{dm}{dx}\right)^2 + (dm/dy)^2} \qquad (2)$$

This function peaks over magnetic contacts under the following assumptions: (i) the regional magnetic field is vertical; (ii) contacts are vertical, and (iii) sources are thick. These assumptions may breakdown in practice, but the approach remains the least susceptible to noise in the data because it only requires the calculations of the two first order horizontal derivatives of the magnetic field. Generally, the theoretical shape of the horizontal gradient magnitude over a contact is given by:

$$\text{HGM} = \frac{k}{h^2 + d^2} \qquad (3)$$

where h is the horizontal distance to the contact, d = depth to the top of the contact and k = a constant. Due to the assumptions of thick sources, the depth estimate made using this procedure represents minimum depth (Olagundoye, 2004; Philips, 1997).

MATERIALS AND METHODS

Nine aeromagnetic maps on a scale of 1:100,000 were acquired from the Nigerian Geological Survey Agency NGSA (formally, Geological Survey of Nigeria, GSN). The maps were compiled from the results of a survey completed in 1974 on behalf of the then GSN. Seven of them were based on data obtained at a nominal flight elevation of 0.762 km above mean sea level while the two others were based on a nominal flight elevation of 0.512km (Table 1). In each case, the flight spacing and tie line spacing were constant at 2km and 20km respectively. The geomagnetic gradient was removed using the International Geomagnetic Reference Field (IGRF) formula for 1st January, 1974. The removal of this gradient as well as other data treatments outlined in this section were achieved with the aid of a suite of computer software programmes acquired from the United States Geological Services, USGS, the details of which have been given by Philips (1997).

The aeromagnetic maps were digitized at 1km intervals to avoid the problem of frequency aliasing and recontoured using software progammes (A2XYZ, P2GRD, DETOUR and CONTOUR(Philips, 1997). The contoured map was found to have the resemblance of the original map and merging of the maps was then carried out in a sequential order using software routines FFTFIL, COMPGRD, BIHARM and JMERGER (Phillips,1997). However, prior to this merger, the data for the two maps that were based on a nominal flight elevation of 0.512km (Table 1) were upward continued to the elevation of 0.762km to remove distortions in the magnetic field caused by the difrences in flight elevations. Fig. 3 shows the total magnetic intensity field map of the study area which is the result of contouring the output of JMERGER.

Table 1. Flight parameters of aeromagnetic maps/sheets

S/N	Sheet name	Sheet number	Flight line direction	Flight line spacing (km)	Tie line spacing (km)	Flight altitude (km)
1	Udi	316	NE/SW	2.0	20.0	0.7621
2	Nkalagu	317	NE/SW	2.0	20.0	0.7621
3	Abakiliki	318	NE/SW	2.0	20.0	0.7621
4	Afikpo	315	NE/SW	2.0	20.0	0.7621
5	Ugep	316	NE/SW	2.0	20.0	0.7621
6	Aba	321	NE/SW	2.0	20.0	0.7621
7	Okigwe	314	NE/SW	2.0	20.0	0.7621
8	Ikot Ekpene	322	NW/SE	2.0	20.0	0.5120
9	Uwet	323	NW/SE	2.0	20.0	0.5120

The same output was reduced – to- the- pole through its input into the F_RTP algorithm (Philips,1997) which had the effect of centering the magnetic anomalies. The reduced-to-the- pole map is shown as Fig. 4.

Anomaly separation into regional and residual components was carried out using the reduced-to-the-pole data and the software SUFIT (Phillips,1997) which is a polynomial fitting algorithm. The expression for the planar surface that corresponded to the assumed regional field, T(x,y), is:

$$T(x, y) = 7800.000 + 0.674x + 0.114y \qquad (4)$$

Where x and y are units of spacing of the digitized magnetic data. The regional field was subtracted from the reduced-to-the-pole map (Fig.4) to produce the residual map of Fig.5 which was then used for the depth estimations.

The batched software programmes MFINIT, MFDESIGN, MFFILTER (Phillips,1997). Were used for the power spectrum depth analysis. For this purpose, the residual map (Fig.5) was subdivided into blocks of 0.5^0 x 0.5^0 and 0.25^0 x 0.25^0 sizes in overlapping positions to produce over sixty grid cells. The data for each cell were used in MFINIT to compute the algorithm of the average power spectrum within a range of frequencies.

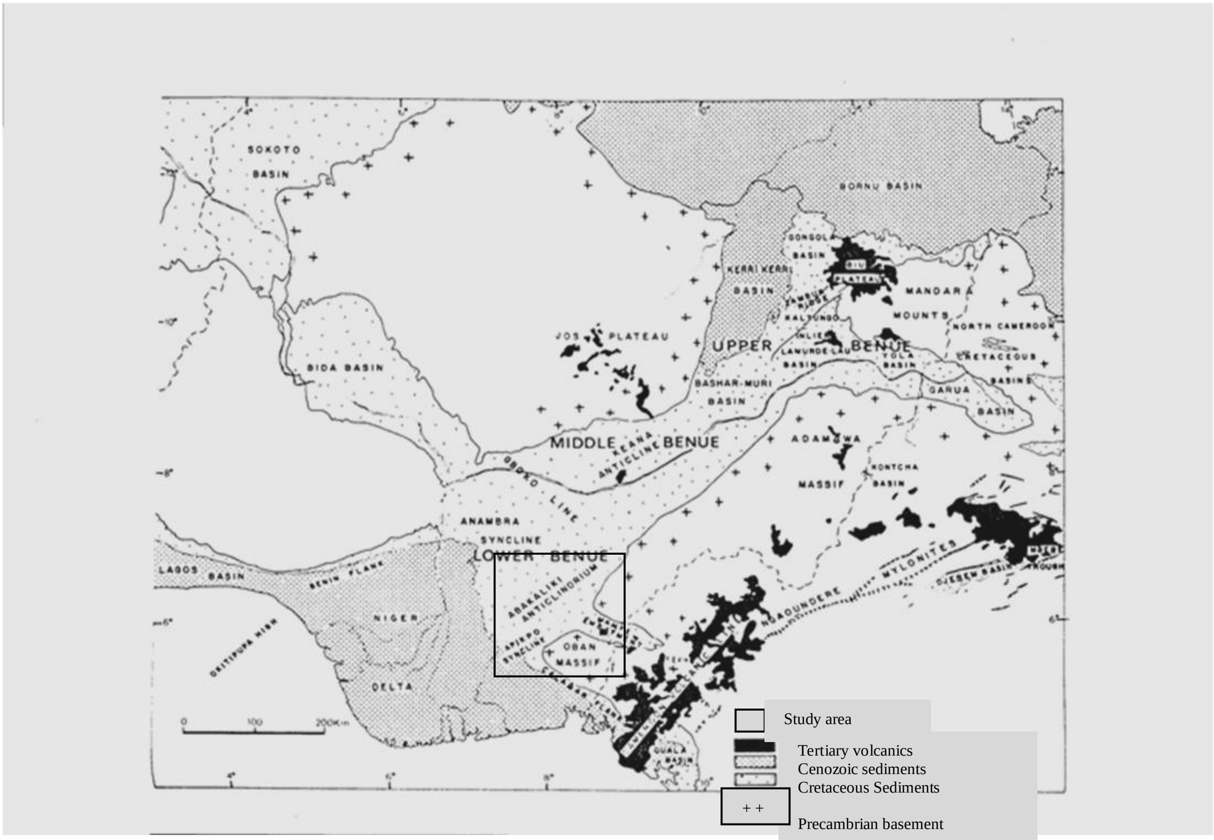

Fig. 1. Outline geological map showing the locations of the Benue trough and the study area (modified after Benkelil, 1982),

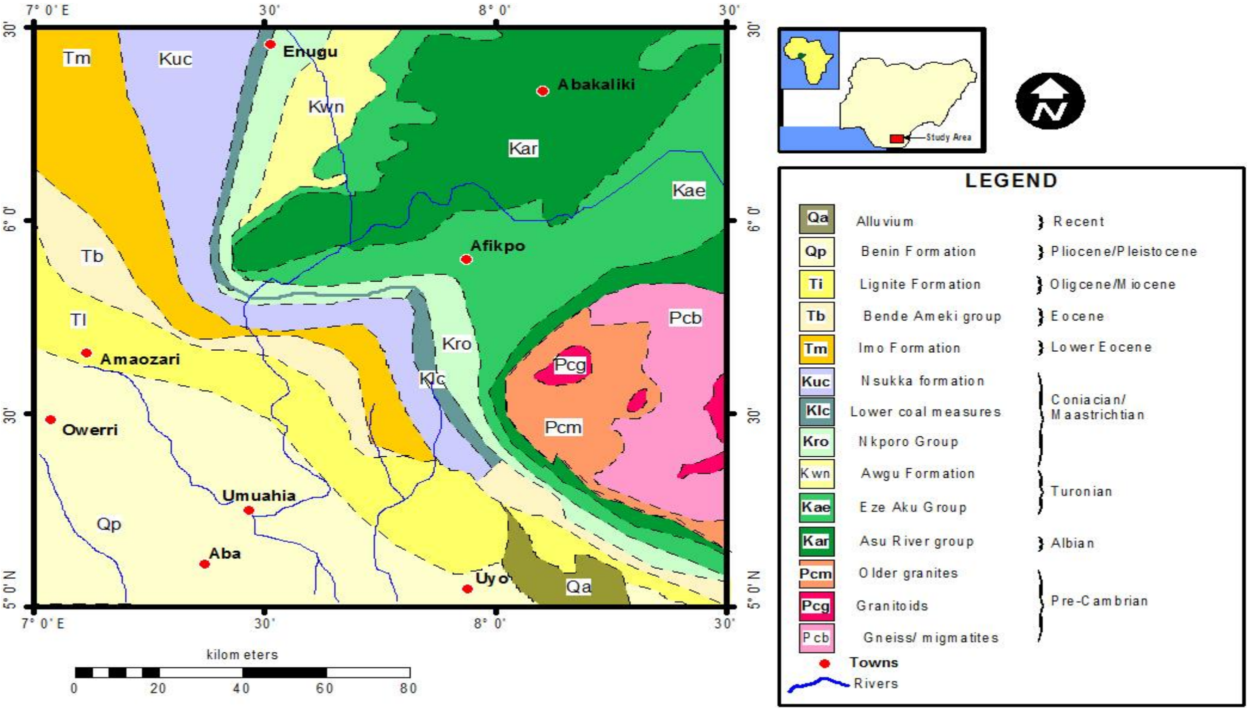

Fig. 2. Geologic sketch map of study area, based on map by Geologic Survey of Nigeria (1994).

The plot of this result was provided by MFFILTER which also filter a least-squares line to a portion of the plot as defined by a selected cut-off frequency (Fig.6).

The slope of this line was used by MFDESIGN to compute the depths to the magnetic source. Depth estimates for all the cells were then contoured to give the power spectrum depth map of Fig.7.

The residual map of Fig.5 was also input into the software programme GRADIENT (Phillips, 1997) which generated gradient solutions. These solutions were used in running HDEP software (Phillips,1997) to produce 892 depth solutions which were subsequently contoured to give the horizontal gradient magnitude depth map of study area (Fig.8).

RESULTS AND DISCUSSION

The computed depths to the magnetic basement in the study area (Fig. 7 and 8) reveal the variable topography of the buried crystalline basement. The power spectrum depth map (Fig. 7) shows that the depth to the magnetic basement ranges from 0.8 to 2.6km. In the northeastern part of the map, east of longitude 8.0^0E and north of latitude 6.6^0N, the magnetic basement depth values decrease eastwards from about 1.3km to 0.8km. The resultant basement high partly corresponds to the southern part of the Abakaliki foldbelt. It is also seen to underlie the north-central part of the map area, close to Nkalagu (Fig. 7). A smaller basement high appears around longitude 7.3^0E, about 40km southwest of Ikot Ekpene. This may be a southernmost extension of the Abakaliki high.

Elsewhere in the power spectrum depth map (Fig.7), the magnetic basement depth values outline a series of depressions/sub-basins. A prominent sub-basin, about 35 to 45km wide, extends for some 150km southwestwards from Afikpo, with magnetic basement depths ranging from 1.4km to 1.8km (Afikpo area), 2.2km (close to Ikot Ekpene) and slightly over 2.2km (at Aba , on the southwestern end). This corresponds to the Afikpo syncline with the greater magnetic basement depth extend in Ikot Ekpene and Aba areas reflecting the influence of sediments infilling the Niger delta.

Two other magnetic basement depressions can be seen on the power spectrum depth map (Fig. 7). These are:

(i) the Nkalagu sub-basin (1.4 to 2.0km), with a northeasterly trend close to the northwestern corner of the map, and

(ii) the Uwet sub-basin (1.4 to 2.2km), with a northwesterly trend close to the southeastern corner. The lateral extent of the Nkalagu feature could not be determined due to inadequate data coverage while that of the Uwet sub-basin was estimated at about 20km x 15km.

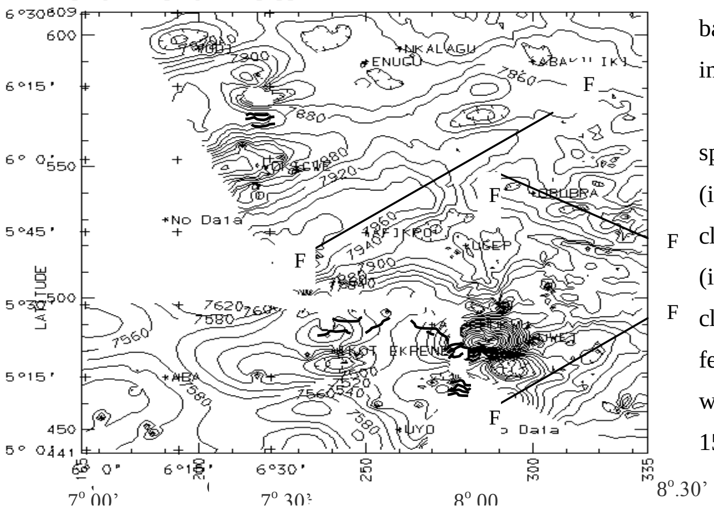

Fig .3. Composite map of total magnetic field intensity (+25,000nT). Contour interval =20nT

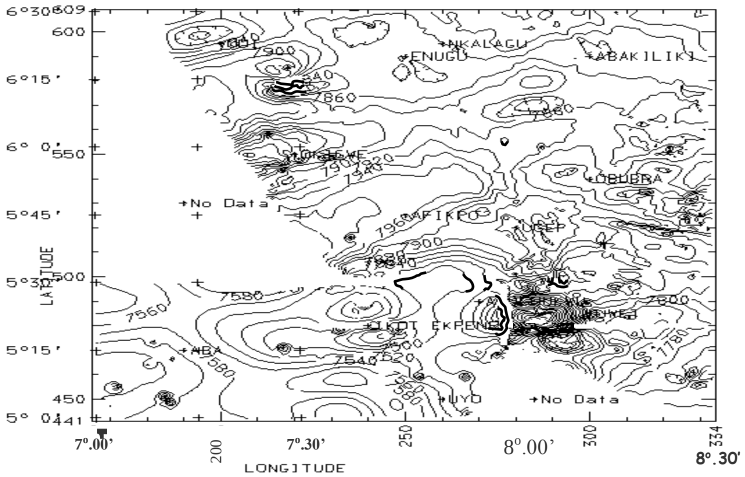

Fig. 4. Reduced- to-the- pole magnetic map. Add 25,000nT to contours which are at intervals of 20nT.

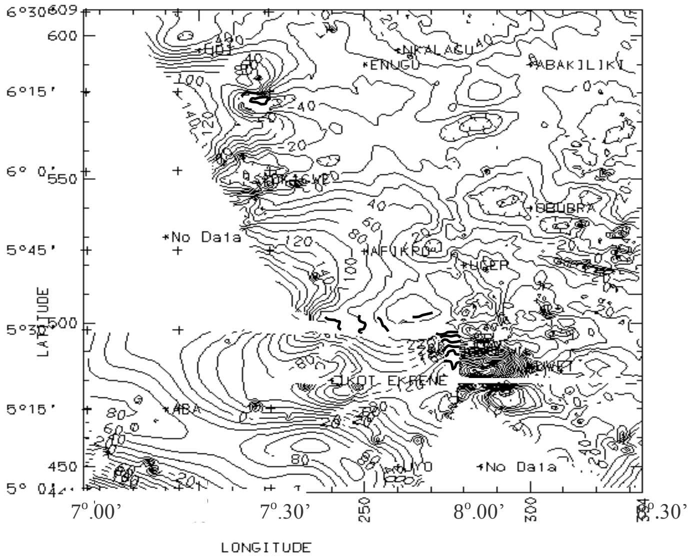

Fig.5. Residual magnetic anomaly map, based on polynomial fitting of reduced-to-the- pole map (Fig.4). Contour interval = 20nT

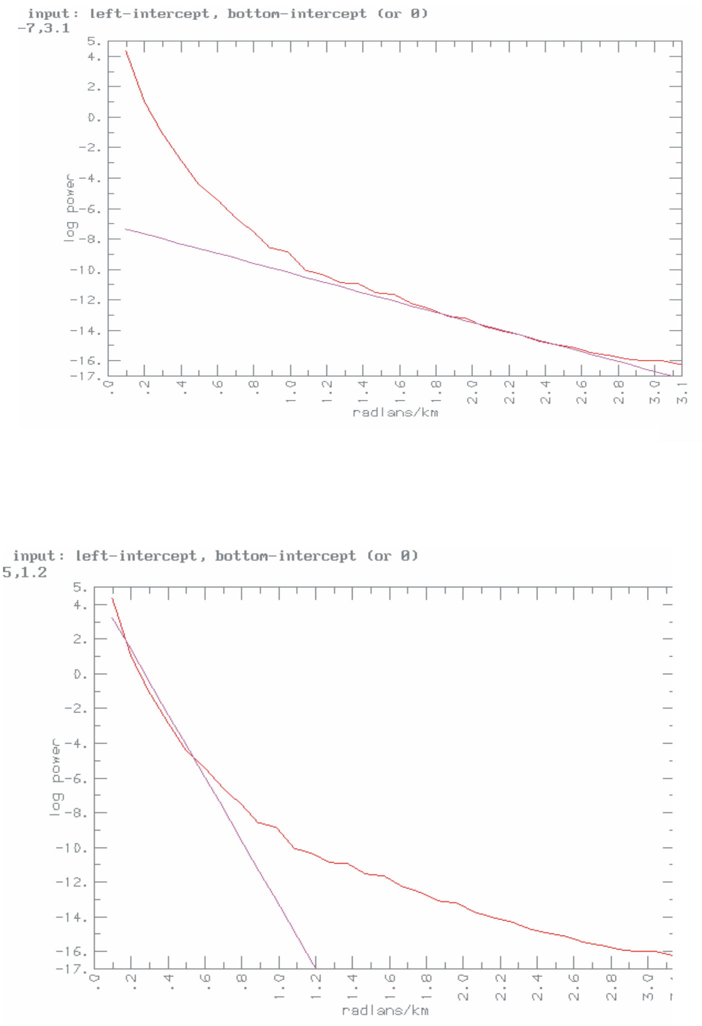

Fig.6. Power spectrum of residual magnetic anomalies illustrated for the Ugep block. Slope of least-squares line is related to the probable depth of the source of the magnetic anomalies which may be a shallow body(top) of a deeply buried body(bottom)

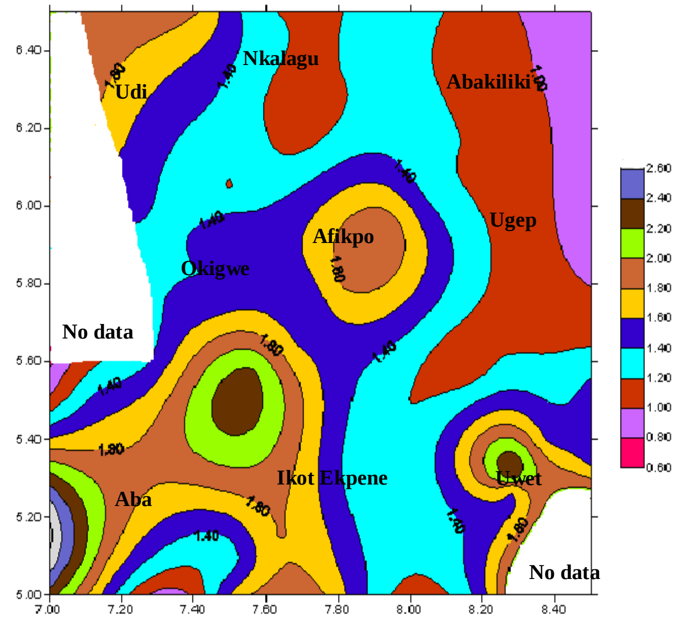

Fig. 7. Magnetic basement depth map in km, based on power spectrum analysis. Contour interval =0. 2km.

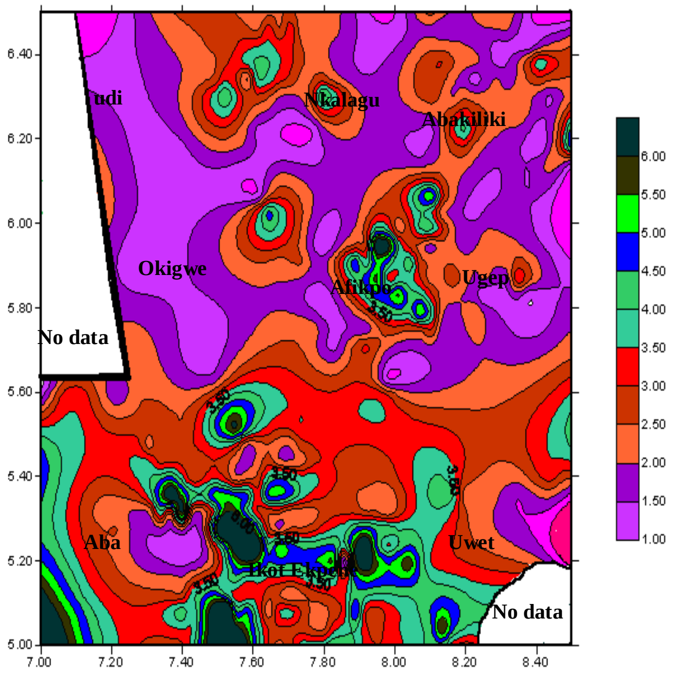

Fig. 8. Magnetic basement depth map (in Km), based on horizontal gradient magnitude (HGM) analysis. Contour interval = 0.5km

In contrast to the power spectrum depth map(Fig.7), the HGM depth map(Fig.8) shows a greater range of magnetic basement depth values, from 1.0 to 6.0km. Here, with the exception of the magnetic basement depressions, the depth to this basement ranges from 1.0 to 2.0km in the northern part of the map area, i.e. beyond latitude 6.6^0N(Fig.8). to the south of this latitude, the magnetic basement depth varies between 2.0 and 2.5km, revealing a southwestward deepening towards the Niger delta.

In addition, the Afikpo sub-basin is shown to be extensive in the HGM depth map(Fig.8), reaching close to Abakaliki and up to the northeastern corner of the map area. However, it is comprised of several smaller sub-basins, each less than 20km in width, with intervening magnetic basement highs. The magnetic basement depth values outling these sub-basins range as follows: (i) 2.5 to 4.5km in the northeastern part(northeast of Afikpo), and (ii) 2.5 to 6.0km in the southwestern part(Afikpo to further southwest of Aba). The Afikpo sub-basin is intersected in the Ikot Ekpene area(southwestern part) by the similarly better outlined Uwet depression (2.5 to 5.0km,Fig. 8) with a northwesterly trend, extending for about 55km from close to the southeastern corner of the map area. This depression has been attributed to a major depocenter in the Calabar flank (Fig.1)

Further more. The Nkalagu sub-basin seen in the northwestern part of the power spectrum depth map (Fig.7) is better outlined in the HGM depth map (Fig. 8) in which it is marked by magnetic basement depths of 2.5 to 4.0km with a lateral extent of about 35km x 14km.

To the south of this depression is the smaller Okigwe sub-basin which is not apparent on the power spectrum depth map (Fig.7).

It is, thus, evident that the depths to the magnetic basement obtained using the HGM approach in the study area are almost twice their counterparts derived using the power spectrum technique. This is especially true in the areas of inferred magnetic basement depressions. For instance, the Afikpo sub-basin is outlined by magnetic basement depths of 2.5 to 6.0km in the HGM depth map (Fig. 8) whereas the same feature is marked by magnetic basement depths of 1.4 to 1.8km in the power spectrum depth map (Fig.7). Similarly, the Uwet sub-basin in the Calabar flank is marked by magnetic basement depths of 2.5 to 5.0km in the HGM depth map (Fig. 8) and by magnetic basement depths of 1.4 to 2.2km in the power spectrum map (Fig. 7). Interestingly, the HGM-derived depths of 2.5 to 5.0km are consistent with well data in the flank which consists of the drilled depths in three wells that have penetrated the crystalline basement: Ikpe-1(2,621m), Ikono-1(3,253m) and Anua-1(3,522m).

In conclusion, the two methods of determing depths to the magnetic basement used in this study corroborated well in revealing the gross structure of the buried crystalline basement which is shown to comprise of basement highs and lows(horst-and-graben structure). However, within the depressions, the depth estimates obtained using the HGM technique seem to be of better accuracy than those computed using the power spectrum approach. Thus, sediment thickness of 2.5 to 5.0km can be expected in the main parts of the Afikpo and Uwet depressions which are therefore potential targets for hydrocarbon exploration in the study area. Finally, in relatively unexplored basins,a combination of at least three techniques of estimating depths to the magnetic basement is recommended for reliable results which should be based on the degree of agreement between the techniques.

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