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Spectral Depth Analysis of Parts of Upper Benue Trough and Borno Basin, North-East Nigeria, Using Aeromagnetic Data

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Abstract: ***Spectral depth analysis of aeromagnetic data covering latitude 9.50 – 12.00 and longitude 9.50 – 12.00, which corresponds to parts of upper Benue Trough and southern Borno Basin, northeast, Nigeria, was carried out for the purpose of investigating the sedimentary thickness beneath the subsurface. The study area was covered by 25 aeromagnetic maps. The aeromagnetic maps were digitized on a 3 km by 3 km grid and later compiled to produce a combined aeromagnetic data file for the area. The 3 km spacing interval imposed a Nyquist frequency of 0.167 km-1 while the data file comprised 7921 data points. The polynomial fitting method was applied in the regional–residual separation. The residual map was later sub-divided into 41 spectral sections. The result of the study shows that the first layer depth was estimated to have ranged from 0.268 km to about 1.08 km while the second layer depth was estimated to have ranged from 2.06 km to about 3.35 km. The highest sedimentary thickness of 3.35 km was found at the northern part of the area and corresponds to areas around Damaturu and Bulkachuwa. These areas may be subjected for further geophysical method like seismic reflection/refraction, so as to ascertain its hydrocarbon potential.***

Keywords: Aeromagnetic data, Spectral, Depth, Sedimentary depth, first and second layer depth.

1. Introduction

The search for mineral deposits and hydrocarbon (oil and gas) has been a major business challenge in Nigeria since the pre-colonial era and the 1960s respectively. The bedrock of Nigeria's economy has been the solid mineral and currently the lucrative oil sector due to its high profitability. Over 80 percent of the country's revenue comes from export and domestic sales of the oil and gas upon which over 140 million growing population depends on. As the hydrocarbon potential of the prolific Niger delta becomes depleted or in the near future may be exhausted due to continuous exploitation, attention needs to be shifted to other sedimentary basins. The Upper Benue Trough and Borno basin in particular is one of those basins being suspected to have high hydrocarbon potential, besides economic mineral deposits concentration. Recently, the petroleum potential of the trough has been of great interest to geologists and geophysicists. The Nigerian government through the Nigerian National Petroleum Corporation (NNPC) and many oil companies had invested heavily in this part of the basin prospecting for oil which remains elusive up to today. However, efforts are still on and more money is still being sunk into the area with the hope of finding oil in the near future. This study will be very useful on a reconnaissance basis for oil and mineral prospecting in the area.

The spectral analysis of aeromagnetic fields over the area would differentiate and characterize regions of sedimentary thickening from those of uplifted or shallow basement and also to determine the depths to the magnetic sources. The results could be used to suggest whether or not the study area has the potential for oil/gas and mineral deposits concentration. This study area is bounded by latitudes 9.50'N to 12.00'N and longitudes 9.50'E to 12.00'E located within the Upper Benue Trough and southern Borno Basin, Northeast Nigeria (Figure 1). It is approximately 275,000 km2 and covered by 25 aeromagnetic maps.

2. Geology of the Study Area

The study area covers extensively the Upper Benue Trough, some parts of Chad Basin (Southern part of Bornu Basin), the Younger Granites (province of Bauchi area) and the Basement Complex, Figure 1 and Figure 2. All the rocks in the area belong either to the Upper Cretaceous or to the Precambrian. All the above mentioned units have already been described in detail by various workers ([1], [2], [3], [4], [5] and [6]). The sandstones of the Upper Benue Trough and the lower part of the Bornu Basin belong to the Upper Cretaceous and they are underlain by the Precambrian rocks of the Basement Complex.

The Upper Benue Trough comprises the area extending from the Bashar-Mutum Biyu line as far north as the "Dumbulwa-Bage high" of [7], which separates it from the Bornu Basin. Early studies of the Upper Benue Trough and Southern Bornu Basin were carried out by [8], [9], [10] and [11]. The basis for all later work was provided by [12] who undertook a regional study of the area covered by the Geological Survey of Nigeria 1/250,000 Series map sheets 25 (Potiskum), 36 (Gombe) and 47 (Lau). The Upper Benue Trough has since become known in greater detail and has been almost entirely remapped through the work of [13], Benkhelil ([14], [15], [16]), [17], Guiraud ([18], [19], [20], [21]) and [7].

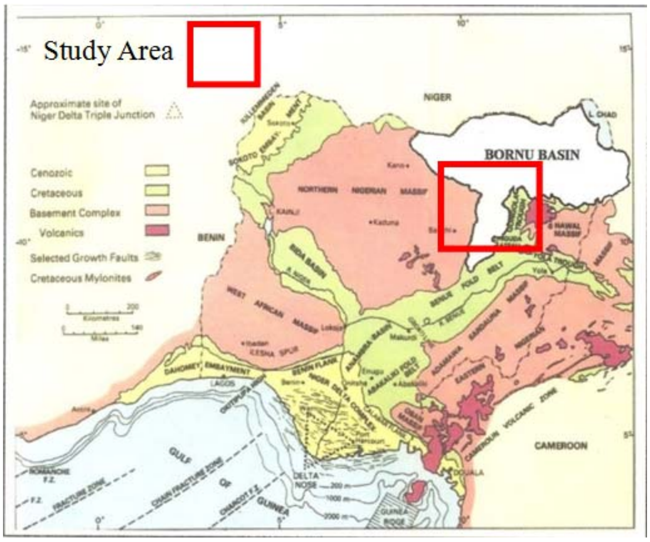


Figure 1: Location of the Study Area (parts of Upper Benue Trough and southern Bornu Basin). Adapted from [22]

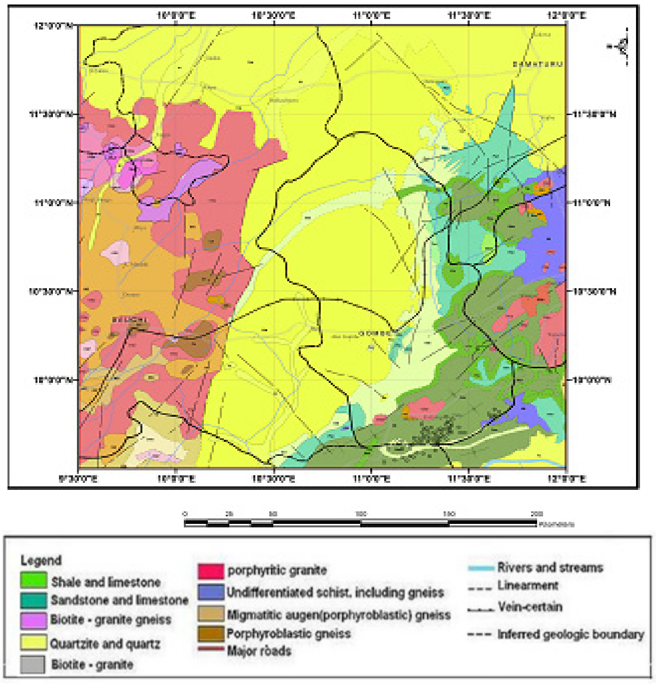


Figure 2: Map of selected profiles for modeling on the geologic map to scale 1:2000000.

The Bornu Basin (or “Maiduguri Subbasin” of [23]) is the south-western part of the Chad Basin (Figure 1). The Cretaceous sediments in the Bornu Basin are almost entirely concealed by the continental Pliocene to Pleistocene Chad Formation ([12]; [11]; [24]) which reaches a thickness of over 1500 m [25]. Descriptions of the Bornu Basin have been given by [10], [26], [23], [27] and [25]. Those parts of the Chad Basin to the north and east were reviewed by [28] with important subsequent accounts having been given by [29] and ([30], [31]). The latter provided detailed descriptions of the concealed east Niger, Bongor, Doba, Dosco and Salamat rifts. The Southern part of the Bornu Basin is covered by the Geological Survey of Nigeria 1/250,000 Series map sheets 25 (Potiskum). [10], [11] and [23] produced the geological maps of parts of the area to the north.

3. Materials and Method

The aeromagnetic dataset used for this study was obtained from the Nigerian Geological Survey Agency as a part of the nation-wide aeromagnetic survey between 1974 and 1980. The magnetic data were collected at a nominal flight altitude of 154.2 m along approximately N-S flight lines (nearly perpendicular to predicted geological strikes in the area), spaced 2 km apart. The component of the field measured was the total magnetic field. The study area is covered by twenty five aeromagnetic maps of total-field intensity in ½º by ½º sheets. These are numbers 83 - 87, 106 - 110, 128 - 132, 149 - 153 and 170 – 174 on a scale of 1:100,000. The magnetic values were plotted at 10nT (nano Tesla) interval. The actual magnetic values were reduced by 25,000 gammas before plotting the contour maps [32]. This means that the value of 25,000 gammas should be added to the contour values so as to obtain the actual magnetic field at a given point. A correction based on the international Geomagnetic Reference Field, IGRF, and epoch date January 1, 1974 was included in all the maps. The data used were digitized on a 19 x 19 grid systems using ILWIS. The spacing imposes a Nyquist frequency of 1/2.895 km, approximately 3.0 km. Thus, the magnetic feature that can be defined by the digitised data has a narrowest width of 3.0 km. This gridding system was supported by previous studies with crustal magnetic anomalies ([33]; [34] and [35]), which shows that the spacing is suitable for the portrayal and interpretation of magnetic anomalies arising from regional crustal structures. Figures 3 (a and b) and 4 (a and b) are the total magnetic intensity map of the study area and the residual magnetic map of the study area respectively.

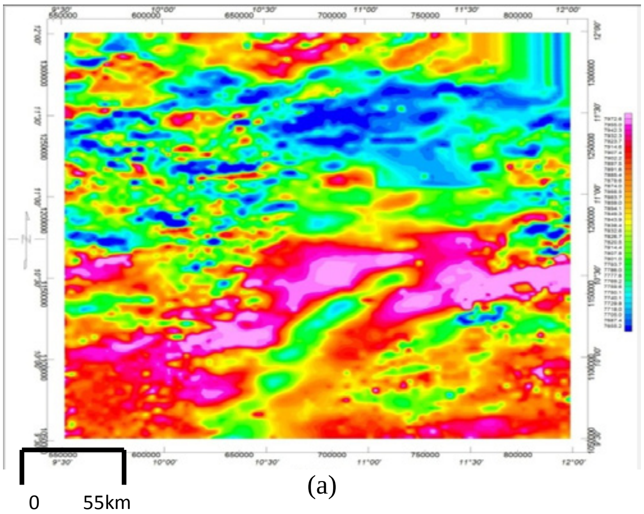
4. Spectral Analysis

The statistical spectral analysis of the residual field data was employed to determine the depths to the buried magnetic sources within the sub surface of the study area. [36] and [37] developed a 2-D spectral depth determination method. Their model assumes that an uncorrelated distribution of magnetic sources exists at a number of depth intervals in a geologic column. The Fourier transform of the potential filed due to a prismatic body has a broad spectrum whose peak location is a function of the depth to the top and bottom surfaces and whose amplitude is determined by its density or magnetization.

The peak wave number (ω′) can be related to the geometry of the body according to the following expression.

$$w' = \frac{\ln\left(h_b/h_t\right)}{h_b - h_t} \quad (1)$$

w' is the peak wave number in radian /ground – unit, h_t is the depth to the top and h_b is the depth to the bottom.



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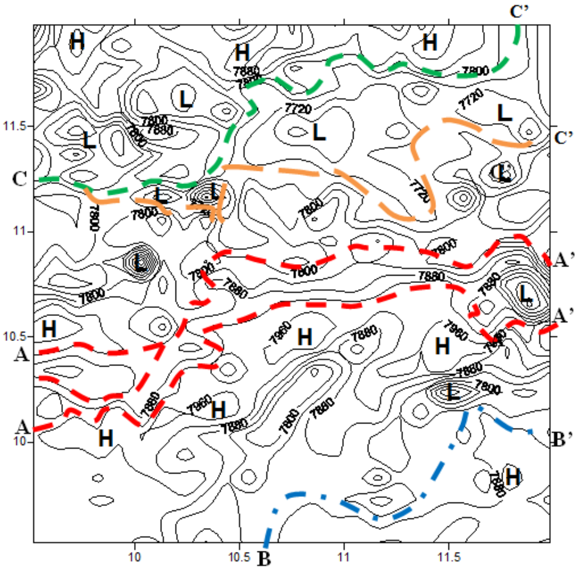
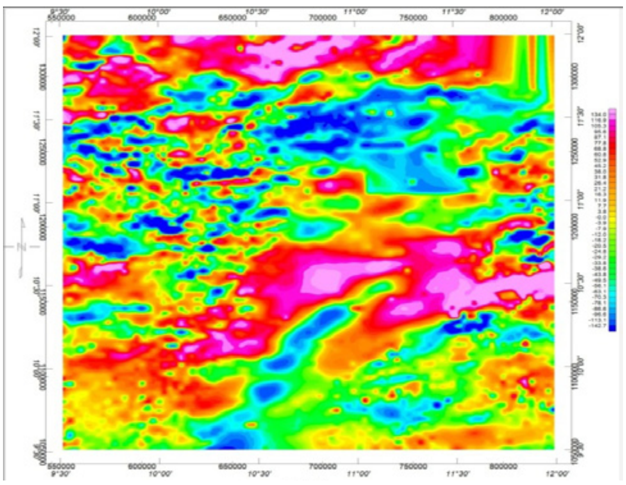


(b)

Figure 3: Total magnetic intensity map of parts of Upper Benue Trough and southern Bornu Basin: (a) was obtained with Oasis and (b) was obtained through Surfer 8. Unit of total magnetic intensity is nano tesla (nT) and contour Interval is 40nT. Magnetic 'Highs' (H) and 'Lows' are depicted with 'H' and 'L' respectively. AA' BB', CC' are the paleo-structures noticed to have passed through the study area as noted by [38]. AA' BB', CC' represents the Romanche, Chain and St. Paul paleo-structures respectively.



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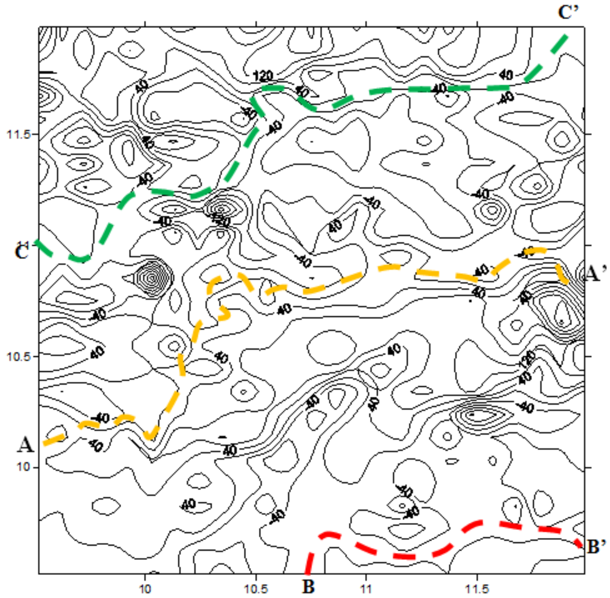


(b)

Figure 4: Residual-magnetic map of parts of Upper Benue Trough and southern Bornu Basin: (a) was obtained with Oasis and (b) was obtained through Surfer 8. Unit of total magnetic intensity is nano tesla and contour interval is 40nT. AA' BB' and CC' are the same as explain in Figure 3. For a bottomless prism, the spectrum peak at the zero wave number according to the expression:

$$f(\omega) = e^{h\omega} \quad (2)$$

Where ω is the angular wave number in radians/ground – unit and h is the depth to the top of the prism. For a prism with top and bottom surface, the spectrum is:

$$f(\omega) = e^{-h_t\omega} - e^{-h_b\omega} \quad (3)$$

where h_t and h_b are the depths to the top and bottom surface respectively. As the prism bottom moves closer to the observation point at surface, the peak moves to a higher wave number. When looking at the spectrum, it is important to note that the amplitude of a deep prism does not exceed the amplitude of the same prism at shallow depth at any wavenumber. The effect of increasing the depth is to shift the peak to lower wavenumbers.

Because of this characteristic, there is no way to separate the effect of deep sources from shallow sources of the same type by using wavenumber filters. The sources can only be distinguished if the deep sources have greater amplitude or if the shallow sources have less depth extent. When considering a line that is long enough to include many sources, the log spectrum of this data can be used to determine the depth to the top of a statistical ensemble of sources using the relationship.

$$Log\ E(k) = 4\pi hk \quad (4)$$

where h is the depth in ground – units and k is the wavenumber in cycles / ground – unit. The depth of an 'ensemble' of source can be determined by measuring the slope of the energy (power) spectrum and dividing by 4π. A typical energy spectrum for magnetic data may exhibit three parts – a deep source component, a shallow source component and a noise component. The residual map of the study area was divided into forty-one (41) blocks of overlapping magnetic sections. Twenty-five of the divisions (sections) covered 55km^2 and sixteen other covers 110km^2. The divisions of residual data/map into 41 spectral sections was done with Oasis montaj and the spectral energies were plotted within it, the *.SPC file obtained were later exported into the Microsoft Excel worksheets one after the other until the total number of 41 spectral (*.SPC) energy files were exported. The Microsoft Excel worksheets file obtained was later used as an input file into a spectral program plot (SPP) developed with Matlab. The total numbers of 41 spectral energies were plotted in Matlab with the developed program. A typical plot of energy against frequency (wavenumber) is as shown in Figure 5. From the slopes of the plot, the first and the second magnetic source depth was respectively estimated using the relations below:

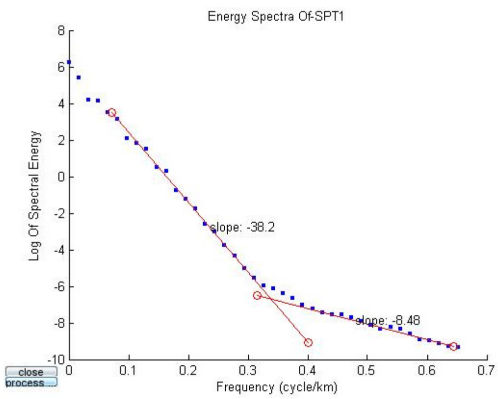
$$z_1 = -\frac{m_1}{4\pi} \quad (5)$$

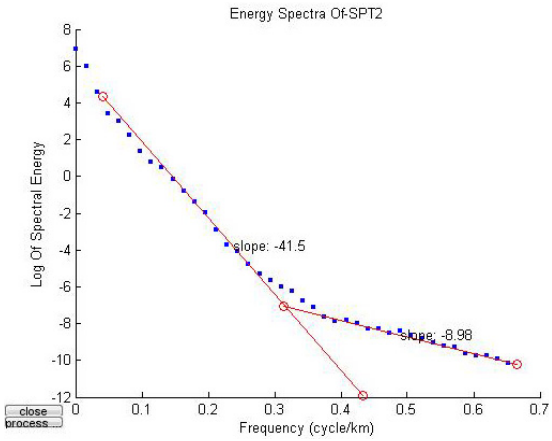
$$z_2 = -\frac{m_2}{4\pi} \quad (6)$$

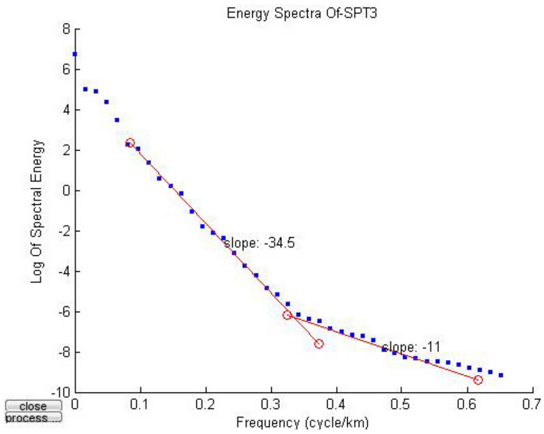
where m_1 and m_2 are slopes of the first and second segment of the plot while z_1 and z_2 are first and second depths respectively (Table 1). The coordinates of each spectral block were obtained by summing the values of the bounding latitude and longitude and averaging it. This was used in plotting the spectral energy against frequency as presented in Figure 5.

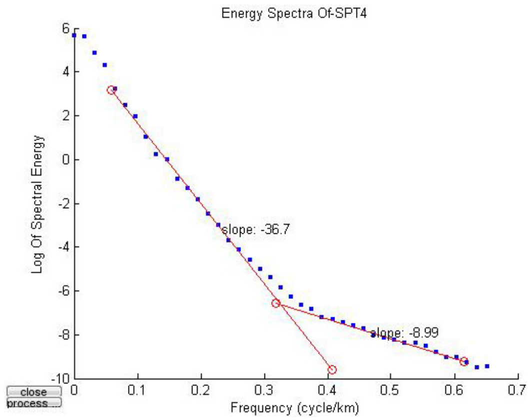
5. Results

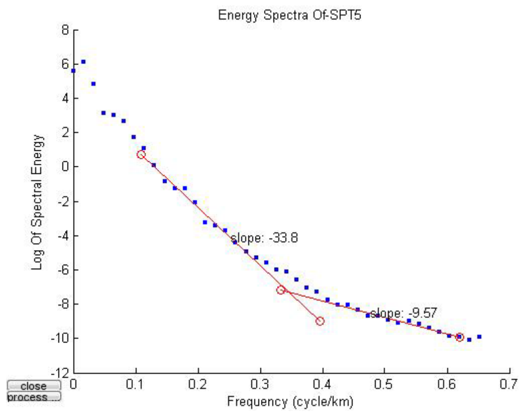
Equation (5) and (6) shows the relationship between the depth (h) to the basement and the decay slopes (m) of the energy spectrum. Table 1 shows the estimated magnetic sources for both the shallow source (depth1) and deeper sources (depth2). The primary sources that account for the first layer depth derived from the statistical spectral analysis are the magnetic rocks that intrude the sedimentary formation. An estimated depth of 0.268km to 1.08km could be observed from the first layer magnetic source's depth. The maximum depth of 1.08km could be found at the north-central part while the minimum depth of about 0.3km could be found at south eastern and south western part of Figure 6.











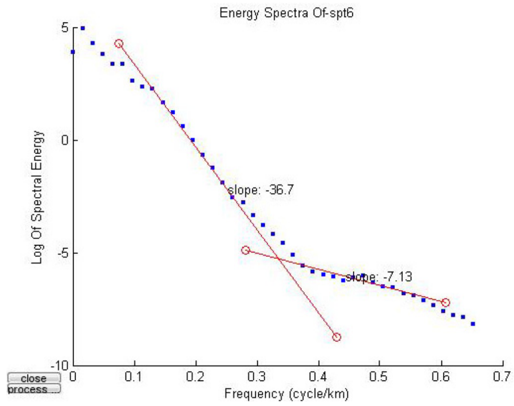
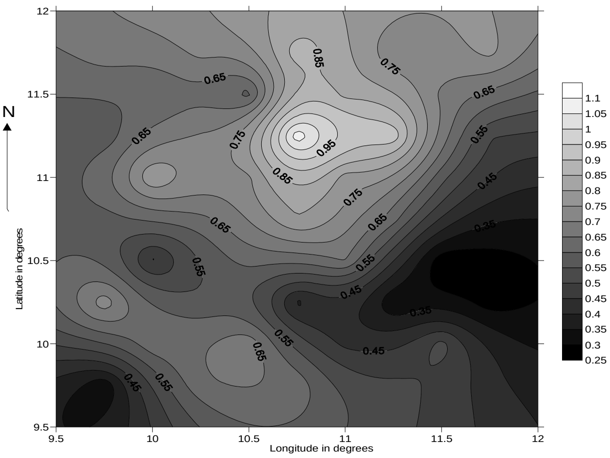


Figure 5: A typical plot of energy spectrum against frequency for sections 1-6



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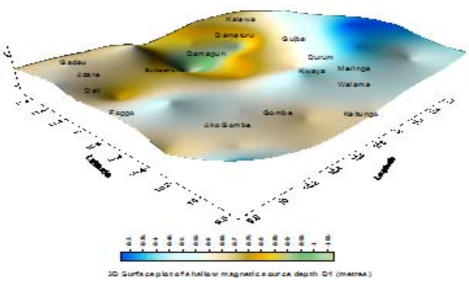


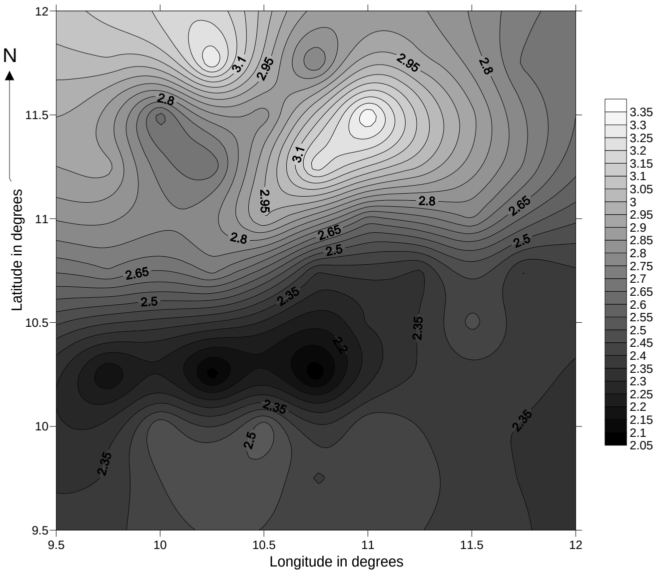
(b)

Figure 6: (a) Contour map of first layer magnetic source (Contour interval is 0.05km) (b) Surface map of shallow magnetic source depth area.

The second layer depth may be attributed to magnetic rocks that are emplaced or intruded into the basement underlying the sedimentary basin. Also, intra-basement features such as fractures could equally contribute to sources that accounted for the second layer depth. This depth to the underlying magnetic basement as estimated from the statistical analysis ranges from 2.06km to 3.35km, Figure 7. The second layer depth thus invariably represents a depth to the underlying magnetic basement rock within the study area and this also represents the average thickness of the sedimentary pile within the study area.

Table1: Estimated depth to the shallow (depth1) magnetic sources and deep (depth2) magnetic sources in km

S/No	*Spectral Section*	*longitude*	*Latitude*	*M1*	*M2*	*h_1(km)*	*h_2(km)*
1	SPT1	9.75	11.75	-8.48	-38.20	0.674729	3.039465
2	SPT2	10.25	11.75	-8.98	-41.50	0.714513	3.302037
3	SPT3	10.75	11.75	-11.00	-34.50	0.875239	2.745067
4	SPT4	11.25	11.75	-8.99	-36.70	0.715309	2.920115
5	SPT5	11.75	11.75	-9.57	-33.80	0.761458	2.68937
6	SPT6	9.75	11.25	-7.13	-36.70	0.567314	2.920115
7	SPT7	10.25	11.25	-8.86	-33.50	0.704965	2.6655
8	SPT8	10.75	11.25	-13.60	-40.60	1.082113	3.230426
9	SPT9	11.25	11.25	-11.70	-37.70	0.930936	2.999682
10	SPT10	11.75	11.25	-6.36	-34.50	0.506047	2.745067
11	SPT11	9.75	10.75	-7.29	-33.90	0.580045	2.697327
12	SPT12	10.25	10.75	-8.00	-34.20	0.636537	2.721197
13	SPT13	10.75	10.75	-10.00	-29.60	0.795672	2.355188
14	SPT14	11.25	10.75	-7.80	-29.40	0.620624	2.339274
15	SPT15	11.75	10.75	-4.55	-29.50	0.362031	2.347231
16	SPT16	9.75	10.25	-9.15	-27.00	0.728039	2.148313
17	SPT17	10.25	10.25	-7.08	-26.00	0.563335	2.068746
18	SPT18	10.75	10.25	-4.88	-25.90	0.388288	2.060789
19	SPT19	11.25	10.25	-3.88	-29.60	0.308721	2.355188
20	SPT20	11.75	10.25	-3.47	-29.70	0.276098	2.363144
21	SPT21	9.75	9.75	-3.92	-29.60	0.311903	2.355188
22	SPT22	10.25	9.75	-7.94	-31.20	0.631763	2.482495
23	SPT23	10.75	9.75	-7.90	-30.10	0.628581	2.394971
24	SPT24	11.25	9.75	-6.38	-30.40	0.507638	2.418842
25	SPT25	11.75	9.75	-5.26	-29.50	0.418523	2.347231
26	SPT26	10.0	11.5	-7.63	-33.00	0.607097	2.625716
27	SPT27	10.5	11.5	-7.35	-35.50	0.584819	2.824634
28	SPT28	11.0	11.5	-10.5	-42.10	0.835455	3.349777
29	SPT29	11.5	11.5	-8.67	-36.60	0.689847	2.912158
30	SPT30	10.0	11.0	-9.98	-34.70	0.79408	2.76098
31	SPT31	10.5	11.0	-9.32	-37.10	0.741566	2.951941
32	SPT32	11.0	11.0	-9.77	-33.00	0.777371	2.625716
33	SPT33	11.5	11.0	-7.14	-34.60	0.568109	2.753024
34	SPT34	10.0	10.5	-5.55	-29.90	0.441598	2.379058
35	SPT35	10.5	10.5	-7.75	-28.80	0.616645	2.291534
36	SPT36	11.0	10.5	-8.19	-29.00	0.651655	2.307447
37	SPT37	11.5	10.5	-3.37	-31.00	0.268141	2.466582
38	SPT38	10.0	10.0	-7.94	-31.40	0.631763	2.498409
39	SPT39	10.5	10.0	-8.59	-31.90	0.683482	2.538192
40	SPT40	11.0	10.0	-5.51	-30.80	0.438415	2.450668
41	SPT41	11.5	10.0	-6.49	-29.60	0.516391	2.355188



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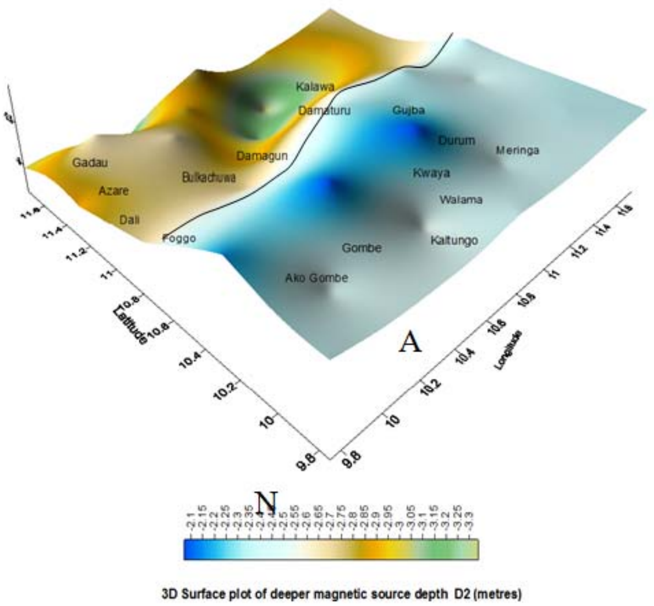

(b)

Figure 7: (a) Contour map of second layer magnetic source (contour interval is 0.05km) (b) Surface map of deeper magnetic source depth area. AA1 shows the supposed separation between Upper Benue Trough and Bornu Basin.

This range of depth is very well in agreement with the work of the previous workers that have used several methods to estimate the thickness of the study area. According to [23] found out that thickness of over 10km was obtained around Maiduguri depression, but less than 5km was later proved from seismic reflection data.; [39] obtained 1.6km to 5km for deeper source around middle Benue, while 60m to 1.2km was obtained for shallow magnetic source; [40] got 2km to 2.62km for deeper source and 70m to 0.63km for shallow source from spectral analysis of upper Benue trough; [41] obtained a maximum depth of 3.39km at Nupe Basin; [42] obtained depth range of 625m to 2.219km for deeper source and an average of 414m for shallow source at upper Benue trough; [43] got a depth range of 420m to 8km southwest of Chad basin. Other workers whom this present work had largely corroborated include: [44], [45], [43], [46], [47], [48] and [49].

Areas around Gombe, Baka, Kwaya and Meringa in Figure 7 correspond to a shallow thickness of about 2 to 2.3 km dept to magnetic source. These areas correspond to areas with highest magnetic values of total magnetic intensity (TMI) map of Figures 3 and residual map of Figure 4.

Figure 6b and 7b shows the surface map of deep and shallow magnetic source depth in a colored range respectively. The supposed AA' in Figure 7b shows delineation between the upper Benue Trough and the Bornu Basin (lower Chad Basin). This line of separation corresponds to the paleo-structure of St Paul shown in Figures 3 and 4 delineated by CC' which corresponds to Dumbulwa-Bage high of [7].

6. Summary and Conclusion

6.1 Sedimentary Thickness and Hydrocarbon Potential

Presence of hydrocarbon and its potential is enhanced by the thickness of the sediments of the basin, and also by the kind of geological structures existing within the basement that form traps for oil and gas.
The highest sedimentary thickness obtained with spectral analysis is 3.35 km. The highest sedimentary thickness was found at the northern part around Damaturu and Bulkachuwa. The basement rocks were exposed around Foggo and Bauchi axes in the basement complex region. The sedimentary thickness is thin around Kaltungo and volcanic area at the eastern part of the survey area.

The boundary between the Bornu Basin and the Upper Benue Trough was successfully delineated through spectral depth determination. The end results of this method shows that Upper Benue Trough was separated from the Bornu Basin at about latitude 11.0^0 N. The supposed separation between Bornu Basin and Benue Trough is a follow up to St. Paul paleo-structure which could have aided the separation of the two basins. This area corresponds to "Dumbulwa-Bage High" of [7].

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