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SPECTRAL DETERMINATION OF DEPTH TO MAGNETIC BASEMENT OF PARTS OF SOUTHERN BENUE TROUGH FOR MINERAL AND HYDROCARBON POTENTIAL

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Abstract

Spectral Analysis was carried out using airborne magnetic data obtained from the Nigeria Geological Survey Agency (NGSA) over Udi, Nkalagu, Nsukka and Igumale with sheet numbers 301, 302, 287 and 288 respectively. The study area between latitude 6° 0' to 7° 0' North and longitude 7° 0' to 8° 0' East was divided into eight spectral blocks and a Fast Fourier Transform was carried out on the spectral blocks with smoothed data to separate the total magnetic intensity data of the windows into their frequency and energy spectrum components. A plot of the log of the spectral energy and the radial frequency was obtained and the gradient used to obtain the shallow and deep depths to magnetic sources. The average shallow depth is 273m while that of the deep depth is 3704m. This implies that the study area is more favourable for mineral exploration while some parts may be suitable hydrocarbon exploration based on further investigations.

Keywords: Spectral Analysis, Fast Fourier Transform, Mineral, hydrocarbon, spectral energy, frequency, depth to magnetic sources.

INTRODUCTION

Sedimentary basins in Nigeria inclusive of the Southern Benue Trough is found to be endowed with mineral resources. Over a score of mineral resources are found in the Trough as reported by the Nigeria Geological Survey Agency. Some of them are; coal, cassiterite, gypsum, uranium, barytes, fluorspar, limestone, ironstone, clay, silver, glass, sulphur, sand, salt, graphite, manganese, mica, lead-zinc and phosphate [1]. Magnetic survey (aero or ground) is important in locating magnetic ore bodies that are buried because of the magnetic susceptibilities of the ores. It can detect these bodies at a depth of tens of kilometers within the earth’s crust though it is limited by the depth where minerals that are magnetic attain their Curie point thereby ceasing to be ferromagnetic [2].

Spectral analysis is one of the methods of determining the depth to magnetic basement of ore bodies as well as the depth of geothermal isotherm beyond which the magnetic materials cease to exhibit magnetism [3]. Magnetic rocks within the earth’s subsurface and the temperature at which they lose their magnetism depends on the magnetic composition of the minerals such as magnetite and hematite [4]. Spectral analysis of magnetic data therefore shows the variation of radially averaged energy spectrum against wave number [5].

The depths to magnetic sources, geothermal isotherms and heat flow have been widely studied in the Lower Benue Trough and other parts of the world using spectral analysis (and other methods). Some of them can be seen in the works of [6 -15].

THE STUDY AREA

The study area lies in the Southern part of the Benue Trough between latitude 6° 0' to 7° 0' North and longitude 7° 0' to 8° 0' East with an undulating topography with an elevation ranging from 200 – 500 m above sea level as shown in Figure 1.

The geology of Benue Trough has been widely discussed in [16-18]. The Southern Benue Trough (SBT) has thick sedimentary sequence composed of Cretaceous to Tertiary rocks. The stratigraphic history of the SBT is characterized by three sedimentary phases namely; the Abakiliki – Benue phase of the Aptian to the Santonian age, the Anambra – Benin phase of the Campanian to the Mid Eocene age and lastly the Niger Delta Phase of the late Eocene to Pliocene age. Figure 2 shows the sedimentary basins in Nigeria indicating the study area.

The study area is composed of the Cretaceous; sandstones, siltstone and shale of the Asu river group. Followed by the Eze-Aku formation, Agwu, Nkporo and Nsukka formations. The Tertiary age is composed of the Imo group, Agbada formation and the Ogwashi-Asaba formation. The youngest of them all is the Benin formation comprising of alluvium deposits, clays and intercalation of sand and clays [19], 20]. Figure 3 shows the local geology of the study area.

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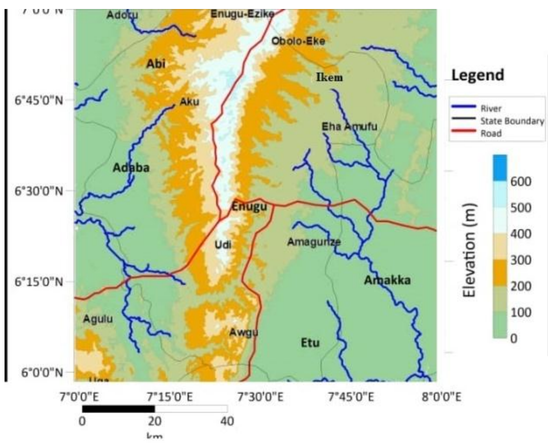


Figure 1. Location Map of the Study Area Showing its Elevation.

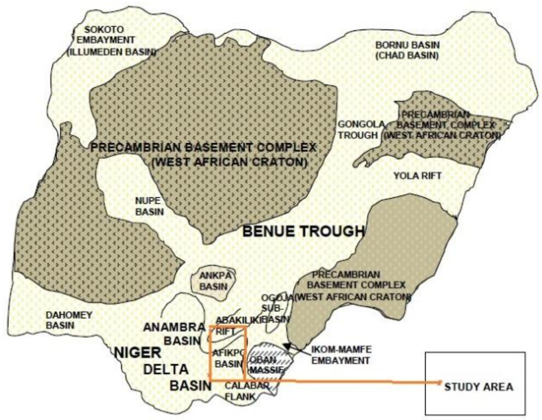


Figure 2: Map of Nigeria showing Basement outcrops and Sedimentary basins. Modified after [21]

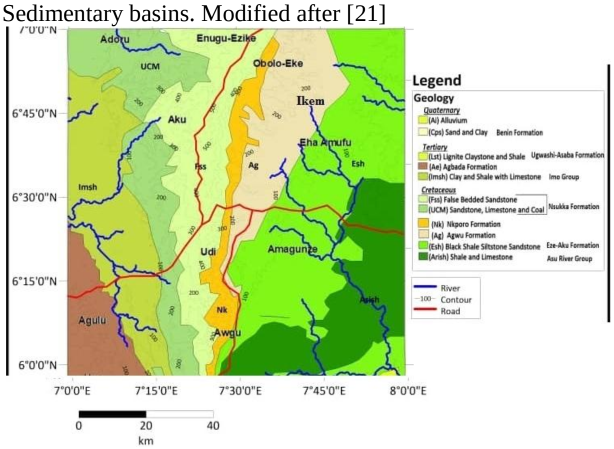


Figure 3. Geology Map of the Study Area

MATERIALS AND METHODS

Four sheets of aeromagnetic data obtained from the Nigeria Geological Survey Agency (NGSA) were obtained for analysis. The sheet names are Udi, Nkalagu, Nsukka and Igumale with sheet numbers 301, 302, 287 and 288 respectively. The survey was carried out at a flying altitude of 80m above the terrain with a flight line spacing of 500m and tie line spacing of 200m along a series of NW-SE. The flight line direction is 45^0 azimuth with an average magnetic inclination and magnetic declination of 9.75^0 and 1.30^0 respectively across the survey.

The data is on a scale of 1:100,000 and the digital data consisting of the Total Magnetic Intensity (TMI) latitude and longitude of the area was windowed from the national grid data base delivered in American Standard Code for Information Interchange (ASCII) file. Using the spectral analysis method, the study area was divided into eight different aeromagnetic grids. The total magnetic intensity data obtained was thereafter windowed into the portions and data smoothened.

A Fast Fourier Transform was carried out on the smoothed data to separate the TMI data of the windows into their frequency and energy spectrum components. Mathematically, the Fourier transform of space domain function $(x,)$ is defined in equation (1) according to [5].

$$\bar{f}(\mu,v)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)e^{-i(\mu x+vy)}dxdy \qquad (1)$$

The reciprocal is given as

$$f(\mathrm{x},\mathrm{y})=\frac{1}{4\pi^2}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\bar{f}(\mu,\mathrm{v})e^{i(\mu x+vy)}dxdy \qquad (2)$$

where μ and v are wave numbers in the x and y directions measured in cycles per metre. A given potential field function in the space domain has a single and unique wave number domain function and vice versa. The function of energy against wave number and direction is called the energy spectrum. The power spectrum $\left|\bar{f}(\mu,v)\right|^2$ and its total energy E_T are related by equation (3).

$$E_T=\frac{1}{2\pi}\int_{-\infty}^{\infty}\left|\bar{f}(\mu,v)\right|^2 d\mu dv \qquad (3)$$

Unlike the infinite area assumed in the above mathematical equations, the geophysical potential data is collected with defined boundaries of the study area. It has been shown by [22] that the log of the energy spectrum of the magnetic source have a linear gradient whose magnitude depends on the depth of the source as seen in equation 4.

$$E_T = e^{-2Zr} \tag{4}$$

where Z and r are, depth and frequency respectively.

Therefore, the radial frequency (r) and the log of the spectral energy were obtained for each windowed portion and the gradient of their linear segments were used to determine the depths to basement using equations 5 and 6. The gradients are usually negative which signifies depth from the subsurface.

$$M_1 = \frac{\Delta(\log E_T)_1}{\Delta r_1} \tag{5}$$

$$M_2 = \frac{\Delta(\log E_T)_2}{\Delta r_2} \tag{6}$$

Two depths deep depth (Z_1) and shallow depth (Z_2) were thereafter obtained using M_1 and M_2 as given in equations 7 and 8.

$$Z_1 = \frac{-M_1}{2\pi} \tag{7}$$

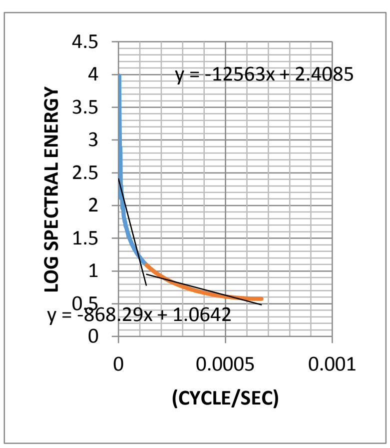
$$Z_2 = \frac{-M_2}{2\pi} \tag{8}$$

RESULTS AND DISCUSSION

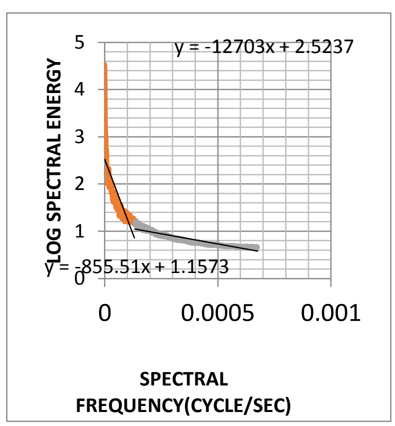
The plots of log spectral energy against spectral frequency for the 8 different blocks are shown in Figure 4. From the spectral plots, two depths were obtained namely; deep depth (Z_1) and shallow depths (Z_2) as shown in Table 1. The shallow depth due to magnetic bodies ranges from 271m to 276m with an average of 272.92m. The deep depth on the other hand ranges from 3319m to 4043m with an average depth of 3704m. The depth to magnetic basement maps obtained from spectral analysis is as shown in Figure 5. From the maps, it is evident that the deepest magnetic bodies are situated in the Northern part of the study area while the Southeastern part has the shallowest anomaly.

Table 1. Depth Estimates of the Study Area from Spectral Plots

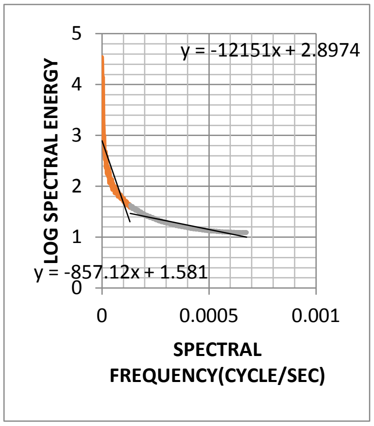
Spectral Block	**Depth (m)**	
	Shallow (Z_2)	**Deep (Z_1)**
1	276.385	3998.927
2	272.317	4043.49
3	272.83	3867.783
4	272.798	3540.879
5	272.604	3621.093
6	272.696	3319.017
7	272.741	3729.637
8	271.012	3512.23
Average	**272.9229**	**3704.132**



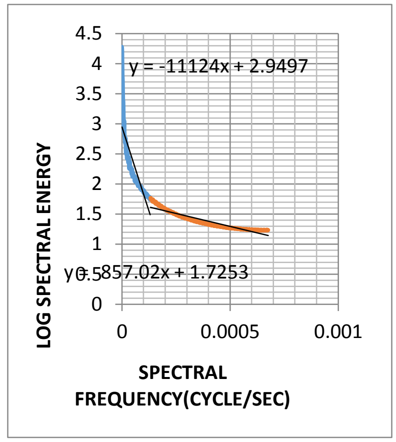
(a) Block one



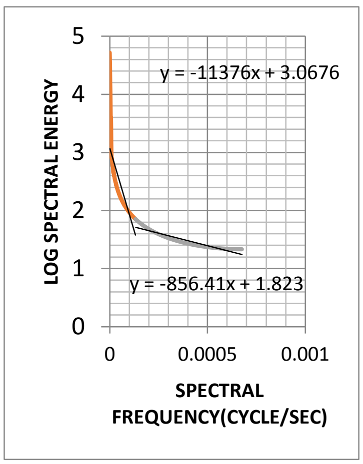
(b) Block two



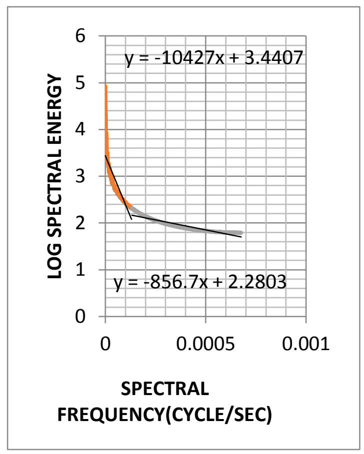
(c) Block three



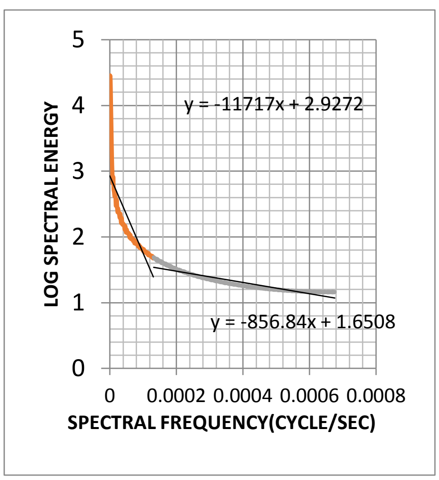
(d) Block four



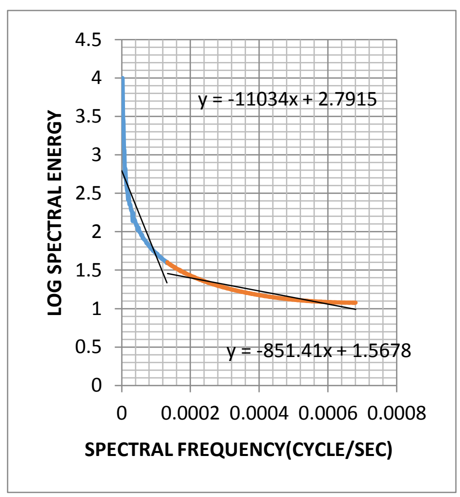
(e) Block 5



(f) Block 6



(g) Block 7



(h) Block 8

Figure 4: Plot of the Log of Spectral Energy Against Spectral Frequency for the Study Area.

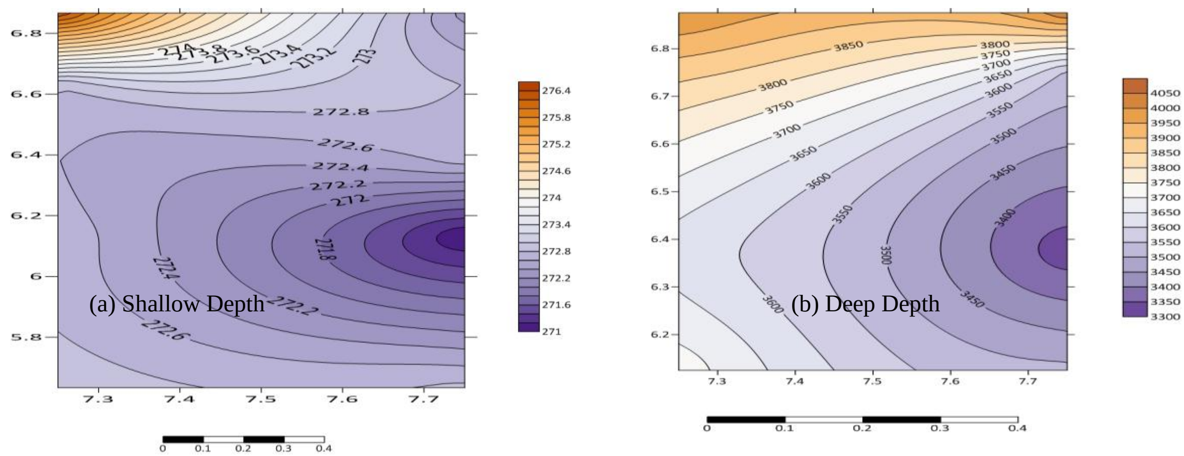


Figure 5: Depth to Magnetic Basement Maps from Spectral Analysis.

According to [23], the minimum thickness of the sediment required for the commencement of hydrocarbon formation is 2 – 7km while that of gas is 3 – 7km below which it is favorable for mineral exploration. However, the occurrence of igneous intrusions in an area with thick sediment indicates an exceedingly high temperature history capable of destroying any hydrocarbon that might have been formed in thermally over mature source rocks [24]. Comparing Figure 5 with Figure 1, the Northern part of the study area like Adoru, Enugu-Esike, Abi and Obolo-Eke may be favourable for hydrocarbon accumulation due to the its deep depth to magnetic bodies. However, further investigation need to be carried out to ascertain the magnitude of their magnetic anomalies as well as their Curie Isotherm. Conversely, Amagunze, Eha-Amufu. Amakka and Agulu will be most favorable for mineral exploration.

CONCLUSION

Spectral analysis is an efficient tool in determining the depth of magnetic bodies. The study area was studied using airborne magnetic data and Fast Fourier Transform was used to obtain the frequency and spectral energy of the eight spectral blocks of the study area. The depth to magnetic sources ranges from 273m to 3704m. The areas with shallow depth to magnetic bodies are most favourable for mineral exploration while areas with deep magnetic bodies may be favorable for hydrocarbon accumulation based on other considerable factors.

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