CURIE DEPTH AND GEOTHERMAL GRADIENT FROM SPECTRAL ANALYSIS OF AEROMAGNETIC DATA OVER UPPER ANAMBRA AND LOWER BENUE BASIN, NIGERIA.

Nigeria Journal of Technological research Vol 12, No 2 2017

Adetona A. A. et al. (2017). Curie depth and geothermal gradient from spectral analysis of aeromagnetic data over Upper Anambra and Lower Benue Basin, Nigeria. NJTR 12(2):20-26.

Curie depth and geothermal gradient from spectral analysis of aeromagnetic data over Upper Anambra and Lower Benue Basin, Nigeria.

Adetona A. A. and Salako, K. A. and A. A. Rafiu. Department of Physics, School of Physical Sciences, Federal University of Technology, Minna, Niger State, Nigeria

Abstract

The resent (2009) aeromagnetic data covering lower part of Benue and upper part of Anambra basins was subjected to one dimensional spectral analysis with the aim of estimating the curie depth and subsequently evaluating both the geothermal gradient and heat flow for the area. Curie point depth estimate obtained were in the range of 25 km to a maximum of 32 km, the maximum values where obtained within the regions of positive magnetic anomalies. The geothermal gradient within this area varies between 320C/km to 800C/km. The highest geothermal gradient is observed around Katakwa at the northern edge, which host the young granitic rocks of central Nigeria and around Lokoja which host undifferentiated old granites of western Nigeria. Heat flow values obtained are between 46mW/m2 and 98 mW/m2. Shallow Curie point depths, high geothermal gradient and high heat flow, located at two geometric basement highs at the western and northern parts, correlate with regions with high concentration of both potassium and Thorium concentrations as observed on the ternary map.

Keywords:- Geothermal Gradient, International Geomagnetic Reference Field (IGRF), Benue Trough
E-mail/Mobile: tonabass@gmail.com; kasalako2012@gmail.com; a.abbass@futminna.edu. +234-08036915982
Received: 2016/09/16
Accepted: 2017/05/05
DOI: **https://dx.doi.org/10.4314/njtr.v12i2.4**

Introduction

Geothermal energy is that energy generated and stored in the Earth. Thermal energy determines the temperature of matter. Earth's geothermal energy originates from the formation of the planet, radioactive decay of minerals, volcanic activity and solar energy absorbed at the surface. The geothermal gradient, which is the difference in temperature between the core of the planet and its surface, drives a continuous conduction of thermal energy in the form of heat from the core to the surface. Geothermal power is cost effective, reliable, sustainable, and environmentally friendly, but has historically been limited to areas near tectonic plate boundaries.

Geothermal energy has been proposed in Nigeria, as an alternative energy source following the discovery of some major anomalies in the Borno basin (Kwaya *et. al.* 2004). Prominent geothermal anomalies in Nigeria thought to be of tectonic origin occur mainly in the Borno Basin. Schoenech and Askira (1987), commenting on the NW-SE trend of the anomalies, suggested a correlation with structural features of the basin, that warm anomalies indicate grabens, while cool anomalies, horsts in the crystalline bottom of the basin. Burke (1976), believed the basin is still tectonically active (Kwaya *et. al.*, 2004). Another geothermal anomaly occurrence in the Sokoto Basin is also considered to originate from heat flow due to neotectonics or from radioactive source known from aero-radiometric surveys results by Hunting Geology and Geosciences, 1976, in the basin (Osazuwa *et al.*, 1981). The radioactive source origin may be the answer for the Sokoto basin since the U-Th occurrences there, is considered traceable under the basin into the large deposit occurring in the Niger Republic where it is being mined. In thermally normal continental regions, the average heat flow is about 60mW/m^2. Values between 80-100mW/m^2 are good geothermal source, while values greater than 100mW/m^2 indicates anomalous conditions (Cull and Conley, 1983; Nwankwo *et. al.*, 2011). The present work is aimed at determining the geothermal anomalies in the basin by estimating the geothermal gradient and heat flow for the area.

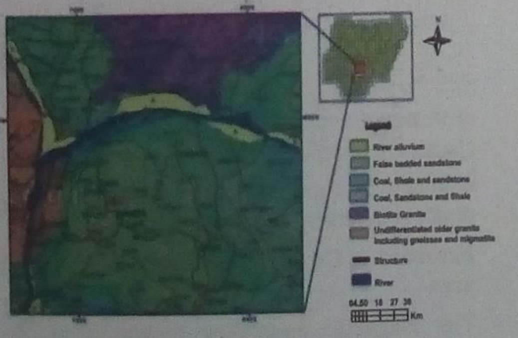
Source of data

A country-wide airborne geophysical survey started in 2003 which has amassed several thousand flying hours. The survey was conducted in two phases. Phase 1 which involve airborne geophysical work, data acquisition, processing and compilation, was carried out by Fugro Airborne Surveys. This was completed in September 2007 and included 826,000 line-km of magnetic and radiometric surveys flown at 500 m profile spacing, 2 km tie-line spacing and 80 m terrain clearance. A total of 24,000 line-km of time-domain electromagnetic surveys, flown at 500 m line spacing and 80 m terrain clearance using the TEMPEST system. Phase 2 completed in August 2009, surveyed blocks not covered in Phase 1. It included 1,104,000 line-km of magnetic and radiometric surveys flown at 500 m line spacing and 80 m terrain clearance. These levels of survey are intensive: often a total of seven aircraft of three different types were active at one time. Phase 1 was financed by the Government of The Federal Republic of Nigeria while Phase 2 was supported by the World Bank. Fugro Airborne Surveys carried out the data acquisition and compilation of this research. Data covering the study area was obtained from "The Nigerian Geological Survey Agency., who is mandated to archive all geological and geophysical datasets for the entire country.

Location of the study area

The study area covers the Lower Benue Trough, the Upper part of Anambra Basin and the basement complexes bounding it at the West and Northern edges. The area is bounded by Latitude 7.0^{0}N to 8.5^{0}N and Longitude 6.5^{0}E to 8.5^{0}E. The physiological features recognized in the area are the river Benue, river Anambra and river Okulu. Twelve aeromagnetic maps covered the study area and are numbered, (227, 228, 229, 230, 247, 248, 249, 250, 267, 268, 269 and 270), A total area of 36,300 square kilometers. The study area touches four states majorly, which are Nassarawa at the upper part, Kogi, Enugu and Benue States at the lower part.

Figure 1: Geology and Location map of the study area.



Geology of Study area.

The Benue Trough is a major structural feature in the Eastern part of Nigeria and an important element in the tectonic framework of Africa. Te entire Benue Trough is believed to have evolved as a result of the continental separation of Africa and South America (King, 1950) and is variously described as a rift system (Crachley and Jones, 1965), an extensional graben system Stoneley (1966) and Wright (1968), a third failed arm or an aulcogen of a three-armed rift system related to the development of domes associated with hotspots Burke and Dewey (1974); Olade (1978). The Benue Trough and indeed middle and upper Benue Trough, is filled with sedimentation (with average thickness of about 5 km) with varied lithological units (Likkason *et al.*, 2005). The Anambra Basin is located in the southern part of the regionally extensive northeast to southwest trending Benue Trough, it is a synclinal structure consisting of more than 5,000 m thick of sedimentation.

Rock type at the western portion of the study area is identified from **Ternary Image** as Undifferentiated Older granite, mainly porphyritic granite granitized gneiss with porphyroblastic granite. Rock type at the Northern portion is identified as Biotite gneiss. False bedded sandstone, coal ,sandstone and shale are the lithologic units at the surface within the sedimentary basin. River Alluvium deposition identified along the river channel. Superimposed geological and the location maps show that Undefferenciated granite mainly porphyritic granite granitized gneiss with porphyroblastic granite covers Obajana, Ajaokuta, Itobe in Kogi State. Biotite granite covers Gadabuke, Katakwa, Nyegba in Nasarawa State. Ayingba, Dekina, Ejule, Angba in Kogi State are covered by False bedded sandstone (Ajali Formation). Coal, sandstone and shale formation identified around Otukpa ,Abejukolo and Ofugo in Kogi State; Abaji in FCT; Udegi and Amaku in Nasarawa State and areas in Benue and Enugu States.

The rivers identified from ternary image were revealed from superimposed maps as river Niger and river Benue. River Niger truncates older granite situated at the western side of the study area. This implies that flow of the river in this area is structurally controlled. A suspected major fault on this lithology allows the passage of the river. This is evident by the same rock lithology at both side of the river.

Method

Curie point depth estimation is based on the spectral analysis of magnetic anomaly data. The basic 2-D spectral analysis method was described by Spector, and Grant (1970). They estimated the depth to the top of magnetized rectangular prisms (Zt) from the slope of the log power spectrum. Bhattacharyya and Leu (1975a, 1975b, 1977) further calculated the depth of the centroid of the magnetic source bodies (Z_0). Okubo *et. al.* (1985) developed the method to estimate the bottom depth of the magnetic bodies (Zb) using the spectral analysis method of Spector, and Grant (1970). Following the method presented by Tanaka *et al.* (1999), it was assumed that the layer extends infinitely in all horizontal directions. The depth to a magnetic source's upper bound is much smaller than the magnetic source's horizontal scale, and the magnetization M(x, y) is a random function of x and y (Blakely, 1995) introduced the power-density spectra of the total-field anomaly$\vartheta_{\nabla T}$:

$$\vartheta_{\nabla T}(K_x,k_y) = \vartheta_m(k_x,k_y)\, X\, F(k_x,K_y) \quad (1)$$

$$F(k_x,K_y) = 4\pi^2 c_m^2 |\emptyset_m|^2 |\emptyset_f|^2 e^{-2|k|Zt}\left(1 - e^{-|K|(Z_b-Z_t)}\right)\left|1 - e^{-|K|(Z_b-Z_t)}\right|^2 \quad (2)$$

where ϑ_m is the power–density spectra of the magnetization, C_m is a proportionality constant, and $\emptyset_m$ and $\emptyset_f$ are factors for magnetization direction and geomagnetic field direction, respectively. The equation can be simplified by noting that all terms except $\emptyset_m$ and $\emptyset_f$are radially symmetric which are constant. If M(x, y) is completely random and uncorrelated, then$\vartheta_m(k_x,k_y)$ is a constant radial average of $\vartheta_{\nabla T}(K_x,k_y)$ becomes:

$$\vartheta_{AT}[\![k]\!] = Ae^{-2|k|Zt}\left(\left|1 - e^{-|K|(Z_b-Z_t)}\right|^2\right) \quad (3)$$

K is wave number and A a constant, if k is less than the thickness of layer we can approximate to:

$$ln\vartheta_{AT}\left(|K|^{\frac{1}{2}}\right) = lnB - |K|Z_t \quad (4)$$

where B is a constant. We could estimate the upper bound of a magnetic source Zt by fitting a straight line through the high-wavenumber part of a radially averaged power spectrum $ln\vartheta_{AT}\left(|K|^{\frac{1}{2}}\right)$ Equation (3) can be rewritten as:

$$\vartheta_{AT}(|K|)^{\frac{1}{2}} = Ce^{-|k|Z0}\left(e^{-|K|(Z_t-Z_0)} - e^{-|K|(Z_b-Z_0)}\right) \quad (5)$$

where C is a constant. At long wavelengths, Eq. (4) can be rewritten as:

$$\vartheta_{AT}(|K|)^{\frac{1}{2}} = Ce^{-|k|Z0}\left(e^{-|K|(-d)} - e^{-|K|(d)}\right) \approx Ce^{-|k|Z0}2|k|d \quad (6)$$

where 2d is the thickness of the magnetic source. From Eq. (5), it can be concluded that:

$$ln\left\{\frac{\vartheta_{AT}(|K|)^{\frac{1}{2}}}{|K|}\right\} = lnD - |K|Z_0 \quad (7)$$

where D is a constant. The centroid of the magnetic source Z_0 can be estimated by fitting a straight line through the low-wave number part of the radially averaged frequency-scaled power spectrum

$$ln\left\{\frac{\vartheta_{AT}(|K|)^{\frac{1}{2}}}{|K|}\right\} \quad (8)$$

From the slope of the power spectrum, the upper bound and the centroid of a magnetic body can be estimated. The lower bound of the magnetic source can be derived (Okubo *et al.*, 1985) and (Tanaka *et al.*, 1999) as

$$Z_b = 2Z_0 - Z_t \quad (9)$$

Since Zb is the lower bound depth of the magnetic body, it suggests that ferromagnetic minerals are converted to paramagnetic minerals due to temperature of approximately 580 _C. Therefore, the obtained bottom depth of the magnetic source, Zb, was assumed to be the Curie point depth. In order to relate the Curie point depth (Zb) to Curie point temperature (580 _C), the vertical direction of temperature variation and the constant thermal gradient were assumed. The geothermal gradient (dT/dz) between the Earth's surface and the Curie point depth (Zb) can be defined by Eq. (8) (Tanaka *et al*,. 1999; Stampolidis *et al.*, 2005; Maden, 2010):

$$\frac{\Delta T}{\Delta Z} = \frac{580°C}{Z_b} \quad (10)$$

Further, the geothermal gradient can be related to the heat flow by using the formula (Turcotte and Schubert (1982); Tanaka *et al.*, 1999):

$$q = \gamma\frac{\Delta T}{\Delta Z} = \frac{580°C}{Z_b} \quad (11)$$

where k is the coefficient of thermal conductivity.From Eq. (11), the Curie point depth is inversely proportional to heat flow.

Estimate of Curie point depth for the study area

The magnetic anomalies measured on the Earth's surface, in which the IGRF field has been removed, result from underlying magnetic materials due to susceptibility. The inclination and the declination of the Earth's main field dominate the magnetic anomalies of the induction field. The correction of reduction to pole (RTE) is often applied to the magnetic anomalies to obtain corrected maps of magnetic anomaly values induced by the inclination of 90^0 and the declination of 0^0. Thus, the anomaly values in corrected maps are with respect to magnetic materials, which lie vertically below.

The depth simulations suggest that the optimal square window dimension is about 10 times the estimated depth (Chiozzi *et al.*, 2005). Thus, the map was subdivided into square subregions of 50 km by 50 km. These subregions are shifting with respect to each other in increments of 27.5 km. The 2-D FFT power spectrum method (Eqs. (3) and (6)) was applied to each subregion. Z_0, the centroid depth of magnetic sources, and Z_t, the top depth of magnetic sources, were derived from the slopes of the longest and second-longest wavelengths of the frequency-scaled power spectrum $ln\left\{\frac{\vartheta_{AT}(|K|)^{\frac{1}{2}}}{|K|}\right\}$ and the radially averaged power spectrum $ln\,\vartheta_{AT}\left(|K|^{\frac{1}{2}}\right)$ respectively. An example of the estimates in a sub-region is shown in Fig. 3.

Results and interpretations

The IGRF corrected TMI map Figure 2, the positive anomaly belts are shown around the western edge of the map which are the old granites rocks of the western parts of Nigeria and the northern edge that represent the young granitic rocks of the central part of Nigeria, other area with positive anomaly around Ayangba and Ankpa down to Otukpo through within the sedimentary region indicate basement susceptibility, regions that shows mixture of negative and positive mixed up are regional geology from orogeny and metaniorphism. The negative anomaly predominantly with the low edge of the study area except some isolated point around kotonkarfi and udegi.

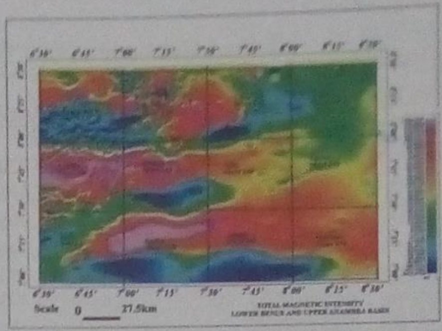


Figure 2: IGRF filtered Magnetic Intensity Map of the study area around the igneous rocks at the north and western edge

Curie point depth (Z_b) map of the study area have shown that the depth varies from 32 km at the western edge to 15 km at the northern part. At the western part the depth varies from 15 km down to 20 km while at the central part around udegi depth ranges from 24 km to 29 km. At the southern edge depth ranges between 25 km to a maximum of 32 km.

The geothermal gradient map of the study area Fig (4) contour values ranges from $32^0C/km$ to $80^0C/km$. The highest geothermal gradient is observed around Katakwa at the northern edge, which host the young granites, where the geothermal gradient ranges from 72 °C/km to 78 °C/km. Low geothermal gradient are at the lower edge of the study area below Idah and Ankpa. Prominent of the note is that at central part of the study area whose values ranges from $38^0C/km$ to 42 °C/km. The low curie depth (15 Km to 25 Km) with high thermal gradient (72 to 78 km) around Katakwa indicates activities of young granitic rock of central Nigeria resulting in noticeable temperature change.

The heat flow values obtained from equal (11) using average thermal conductivity of y = 2.978 $Wm^{-1}K^{-1}$ (Wu *et. al.*, 2013) shown in Fig (5) agrees with the values from curie point depth and geothermal gradient. The high heat flow obtained at the north around Katakwa 86 W/m^2 to $98mW/m^2$ and around Lokoja (84 W/m^2 to 90 W/m^2) at the western edge. This anomalous high heat flow level was observe.

Table:1 Curie point depth, Geothermal gradient, and Heaat flow values.

NO	LONG	LAT	Curie-Point(km)	Geothermal radient(^{0}c/km)	Heat Flow(nW/m^2)
1	6.5	8.5	22.8	25.43859649	63.59649123
1	6.625	8.375	25.82042541	22.46283672	56.1570918
2	6.875	8.375	18.37602973	31.56285708	78.90714269
3	7.125	8.375	14.99557874	38.67806706	96.69516764
4	7.375	8.375	19.3066216	30.0415066	75.10376649
5	7.625	8.375	17.4636639	33.21181646	83.02954114
6	7.875	8.375	19.79338128	29.30272457	73.25681142
7	8.125	8.375	18.76436779	30.90964782	77.27411955
8	8.375	8.375	22.40670545	25.88510843	64.71277106
9	6.625	8.125	16.81616993	34.49061245	86.22653112
10	6.875	8.125	20.04397353	28.93637826	72.34094565
11	7.125	8.125	25.72031136	22.55027133	56.37567833
12	7.375	8.125	24.91527006	23.27889678	58.19724195
13	7.625	8.125	24.91180425	23.28213541	58.20533853
14	7.875	8.125	24.11284644	24.05356835	60.13392088
15	8.125	8.125	24.29022741	23.8779156	59.69478899
16	8.375	8.125	23.22794496	24.96992313	62.42480783
17	6.625	7.875	18.58943871	31.20051171	78.00127926
18	6.875	7.875	24.71039646	23.47190183	58.67975458
19	7.125	7.875	23.57693056	24.60031846	61.50079614
20	7.375	7.875	27.80205802	20.86176497	52.15441242
21	7.625	7.875	28.55557989	20.31126674	50.77816685
22	7.875	7.875	21.30217014	27.22727291	68.06818227
23	8.125	7.875	23.11797447	25.08870319	62.72175798
24	8.375	7.875	20.19386189	28.72159883	71.80399708
25	6.625	7.625	16.81833912	34.48616394	86.21540985
26	6.875	7.625	18.01633956	32.19299892	80.48249731
27	7.125	7.625	24.94045214	23.25539235	58.13848088
28	7.375	7.625	21.45003067	27.03958838	67.59897094
29	7.625	7.625	20.31915801	28.54448987	71.36122466
30	7.875	7.625	22.45676247	25.82740948	64.56852371
31	8.125	7.625	23.72594636	24.44581098	61.11452746
32	8.375	7.625	22.41017126	25.88110521	64.70276302
33	6.625	7.375	16.28994471	35.6047863	89.01196574
34	6.875	7.375	25.03825565	23.164553	57.9113825
35	7.125	7.375	25.24428451	22.97549767	57.43874417
36	7.375	7.375	23.30056638	24.89209878	62.23024696
37	7.625	7.375	20.30642562	28.56238764	71.40596909
38	7.875	7.375	27.25369246	21.28151996	53.2037999
39	8.125	7.375	20.19676228	28.71747422	71.79368554
40	8.375	7.375	21.2567342	27.28547079	68.21367696
41	6.625	7.125	26.59566355	21.80806653	54.52016631
42	6.875	7.125	30.43042512	19.05987175	47.64967937
43	7.125	7.125	21.1913271	27.36968748	68.42421869
44	7.375	7.125	21.58389045	26.87189325	67.17973312
45	7.625	7.125	28.71155173	20.20092837	50.50232093
46	7.875	7.125	30.83467867	18.80999008	47.0249752
47	8.125	7.125	25.82042541	22.46283672	56.1570918
48	8.375	7.125	26.0027346	22.3053463	55.76336574

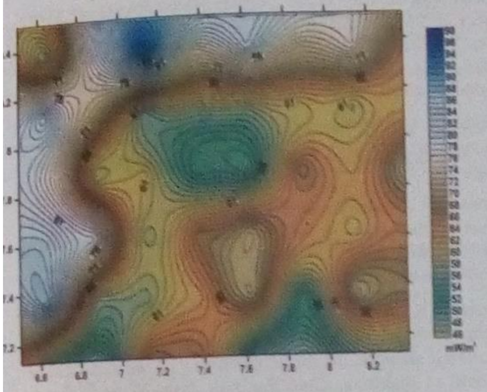


Figure 3: Curie Depth Map of the study area

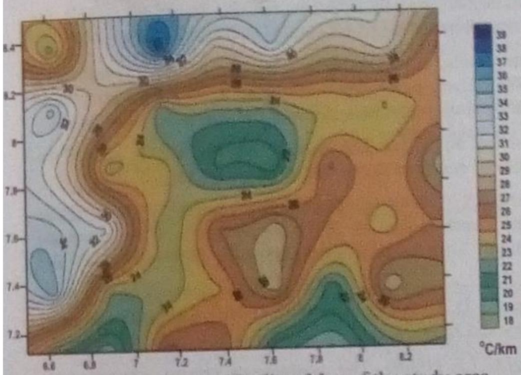


Figure 4: Geothermal Gradient Map of the study area

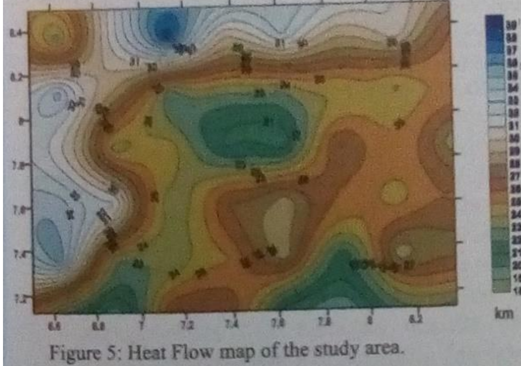


Figure 5: Heat Flow map of the study area.

Correlation of Geothermal gradient and ternary map.

The ternary map of the study area Figure 6, which is obtained by combining the potassium, thorium and uranium concentration of the area shows a striking correlation between the region where the high geothermal gradient is observed and where the potassium and uranium concentrations are high at the northern edge of the area which host the Biotite granite equally at the western edge of the study area around Lokoja which host undifferentiated old granites of western Nigeria, shows relatively high concentration of potassium and thorium. This indicate that the source of high geothermal values in this region can be traced to the contents of the geological structures.

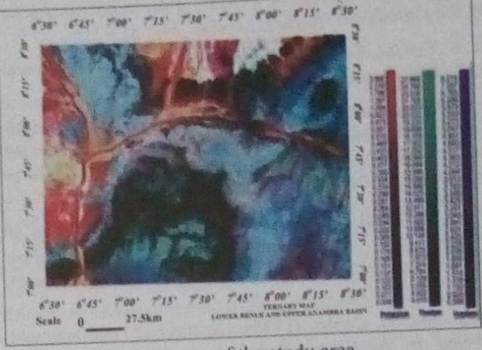


Figure 6: Ternary map of the study area

Conclusion

The IGRF removed Aeromagnetic data of lower Benue and upper part of Anambra basins was employed to the Curie point depth (Z_b) from spectral analysis, estimates obtained shows that the curie point depth for the area ranges from 14 km to 30 km with the maximum value obtained around Idah and Otukpa whjle the minimum value is obtained at the upper part of Gadabuke this curie point depths indicate depth of the bottom of magnetic source. The values for the Thermal gradient (table 1) varies from 36^{0}c/km to 78^{0}c/km figure (6) with the high values occurring at the Northern end and the Western end of the study area where outcrop of magnetic rocks are observed on the geology map figure (1). High heat flow values observed where Curie point depths are shallow, which are located at two geometric basement highs at the western and northern parts. Correlating the heat flow and geothermal results with the ternary map figure (8) it is observed that high geothermal and heat flow values occur within regions with high concentration of both potassium and Thorium concentrations

References

Bhattacharyya, B. K.. and L. K. Leu (1975a). Analysis of magnetic anomalies over yellow stone national par mapping and curie point isothermal surface for geotherm reconnaissance. *Journal of Geophysical Research.* 8 4461–4465.

Bhattacharyya, B.K.. and L. K. Leu (1975b). Spect analysis of gravity and magnetic anomalies due to tw dimensional structures. *Geophysics* 40: 993–1013.

Bhattacharyya, B.K. and L. K. Leu (1977). Spectral analysis of gravity and magnetic anomalies due to rectangular prismatic bodies. Geophysics. 42: 41–50.

Blakely, R.J. (1995). *Potential Theory in Gravity and Magnetic Applications.* Cambridge University Press, Cambridge.

Burke, K. and J. F. Dewey (1974). Two plates in Africa during the Cretaceous. *Nature. London.* 249: 313-315.

Burke, K. (1976). The Chad Basin: an active intra-continental basin. *Tectonophysics* 36. 197-206

Chiozzi, P., Matsushima, J., Okubo, Y., Pasquale, V., and M. Verdoya (2005). Curie-point depth from spectral analysis of magnetic data in central–southern Europe. *Phys. Earth Planet. Inter.* 152: 267–276.

Cratchley C. R and G. P. Jones (1965). An interpretation of the Geology and Gravity Anomalies of the Benue Valley Nigeria. *British Oversea Geol. Survey Geophysics* Paper no1:126

Cull, J. P. and D. Conley (1983). Geothermal Gradients and Heat Flow In Australian Sedimentary Basin. *Journal of Australian Geology & Geophysics*, 8: 32-337.

King, L. C. (1950). Outline and Description of Gondwanaland- *Geological Magazine*. 87, 353-359.

Kwaya, M. Y., Schoeneich, K. and Ikponkonte, A.E. (2004). Thermal water in Bornu basin. Bornu. *Journal of Geology*, 3, 21 29.

Likkason, O. K., Ajayi, C. O Shemang, E. M and E. F. Dike, (2005). Directional filtering and spectral sanalysis of aeromagnetic Data over the Middle Benue Trough, Nigeria. *European Journal of Scientific Research*. 2, 76-112.

Maden, N. (2010). Curie-point depth from spectral analysis of magnetic data in Erciyes stratovolcano (Central TURKEY). *Pure and Applied Geophysics*. 167: 349–358

Nwankwo, L.I., Olasehinde, P.I. and C. O. Akoshile (2011). Heat Flow Anomalies from the Spectral analysis of Airborne Magnetic data of Nupe Basin, Nigeria. *Asian Journal of Earth Sciences, 4: 20-28.*

Okubo, Y., Graf, R. J., Hansen, R. O., Ogawa, K and Tsu, H (1985). Curie point depths of the Island of Kyushu and Surrounding areas, Japan, *Geophysics*, 50, 481-494.

Olade, M. A. (1978). Early cretaceous basaltic volcanism and initial continental rifting in benue trough. *Journal of Mining Geology* 16, 17-25

Osazuwa, I.B., Ajakaiye, D. E. and P.J.T Verheijen (1981). Analysis of the structure of Part of the Upper Benue Rift Valley on the Basis of New Geophysical Data. *Earth Evolution Sciences* 2: 126-135.

Schoenech, K and M. T Askira (1987). Preliminary geothermal outline of the Nigerian part of the Chad Basin. *International seminar on water resources of the Lake Chad Basin* held at Njamena, Chad Republic from 3rd to 5th June, 1987.

Spector, A., and F. S Grant. (1970). Statistical models for interpreting aeromagnetic data. *Geophysics*, 35, 293-302.

Stampolidis, A., kane, I., Tsokas, G. N. and Tsourlos, P. (2005). Curie point depths of Albania inferred from ground total field magnetic data. *Surveys in Geophysics*, 26, 461-480.

Stoneley, R, (1966). The Niger Delta region in the light of the theory of continental drift Geol. *Mag* 103, pp 385-397

Tanaka A., Okubo Y. and O. Matsubayashi (1999). Curie Point Depth based on Spectrum analysis of the magnetic Anomaly Data in East Southeast Asia. *Tectonophysics* 306: 461-470

Turcotte, D. L. and G. Schubertn (1982). Geodynamics. John Wiley and Sons, New York.

Wright, J.E (1968). The geology of church stretton area. Institute of geological sciences (geological survey of Great Britain), vi +87p., with 4 figs. H.M.S.O., London.

Wu, P., Christidis, N. and P. Scott (2013). Anthropogenic impact on earth's hydrological cycle. *Nature climate change* 3: 807-810.