CURIE ISOTHERM DEPTH AND HEAT FLOW DEDUCED FROM SPECTRAL ANALYSIS OF MAGNETIC DATA OVER MONKIN AND ENVIRONS, NORTH-EASTERN NIGERIA.

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ABSTRACT

The depth to Curie point was calculated from 16 overlapping blocks in Jalingo and Environs. The depth to the top (Z_t) of magnetic sources varies from 0.3 km to 0.4 km and the centroid depth (Z_O) varies from 0.9 km to 5.3 km in the region 18.9 to 33.0 km, The objective of this study is to understand the nature and extend of regional geothermal system at depth beneath the Jalingo and Environs by constructing a Curie isotherm. Spectral analysis of the data in conjunction with heat flow information, revealed an almost inverse linear relationship between heat flow and Curie depths. This was used to construct Curie isotherm from the existing heat flow data. The results showed that, Curie depth in the area ranges between 1.72km and 9.8km, with an average heat flow of 319 mWm^{-2}. These are quite a shallow depths and high heat flow. Which resulted from upwelling magma in the tectonically active Cameroon Volcanic line (CVL) in the study area. The most recent eruption occurred in this area around March/April 1999. These results are consistent with the existing geothermal and geotectonics regime and may be economically good alternative source for geothermal reservoir exploration for energy

KEY WORDS: Geothermal reservoir, Energy, Volcanic line, Heat flow.

INTRODUCTION.

The study area is located between latitude 8^o 00' and 9^o 00'N and longitude 11^o 00' and 12^o 00'E, North Eastern Nigeria. The area is characterised by rugged terrain. It is one of the crystalline pre-Cambrian basement blocks in Nigeria. The study area is was subjected to periods of regional metamorphism, tectonism and magmatism (Volcanism) which led to the development of fractures and faults as well as the emplacement of intrusive and dyke like structures. Ofoegbu et al (1992).

The objective of this study is to understand and investigate the extent of local geothermal system beneath the study area to utilize it as an alternative source for geothermal energy as well as to determine the tectonic activities.

The assessment of variations of the Curie isotherm of an area can provide valuable information about the regional temperature distribution at depth and the concentration of subsurface geothermal energy (Tselentis 1991). One of the important parameter that determines the relative depth of the Curie isotherm with respect to sea level is the local thermal gradient. I.e. heat flow (Nafiz, 2009). Measurements have shown that a region with significant geothermal energy is characterised by an anomalous high temperature gradient and heat flow ((Tselentis 1991). It is therefore to be expected that geothermically active areas will be associated with shallow Curie point depth (Nuri et al 2005). It is a known facts that the temperature inside the earth directly controls most of the geodynamic processes that are visible on the surface (Nwankwo et al 2011).In this regard, heat flow measurements in several parts of African continent have revealed that the mechanical structure of the African lithosphere are variable (Nur et al 1999).

The idea of using aeromagnetic data to estimate Curie point depth is not new and it has been applied to various parts of the world, either by analyzing isolated magnetic anomalies due to discrete sources or employing the frequency domain approach. The present paper utilizes spectral analysis to estimate the to Curie isotherm depth and heat flow to determine the geothermal history of the region.

Geology of the study area

The geology of the study area consists of various rock units which have been reported to occur in the study area, geological survey of Nigeria (2006) (Fig.1). It is underlain by Precambrian basement rocks, remobilized by the Pan-African episode (600-500 ma) and uplifted relative to the surrounding area (Nnange et al 2001)

The major rock unit includes;

(a) Undifferentiated granite, migmatites, granite gneiss, porphyroblastic gneiss, Medium to coarse grained biotites and fine grain biotites granite.

(b) Felspathic calcareous Sandstone, shale limestone.

(c) Cenozoic Volcanic rocks(the younger basalts).

Most of these rock unit were subjected to periods of regional metamorphism, tectonism and magmatism which led to the development of fractures and faults as well as the emplacement of intrusive and dyke like structures(Doleritic intrusive). Ofoegbu et al (1992). The study area is cut by a faults trending NE-SW, the fault is part of the ENE-WSW Pan-African Central African Shear Zone on the Adamawa massif, that extend to some kilometres to Cameroon down to Sudan, Nnange et al (2001).

The younger basalt in this area belongs to the Cenozoic volcanic rocks of Cameroon volcanic line (CVL), the Volcanics range from basalts to trachytes and composed basically of alkali basalt (ghongonmu et al., 1999)

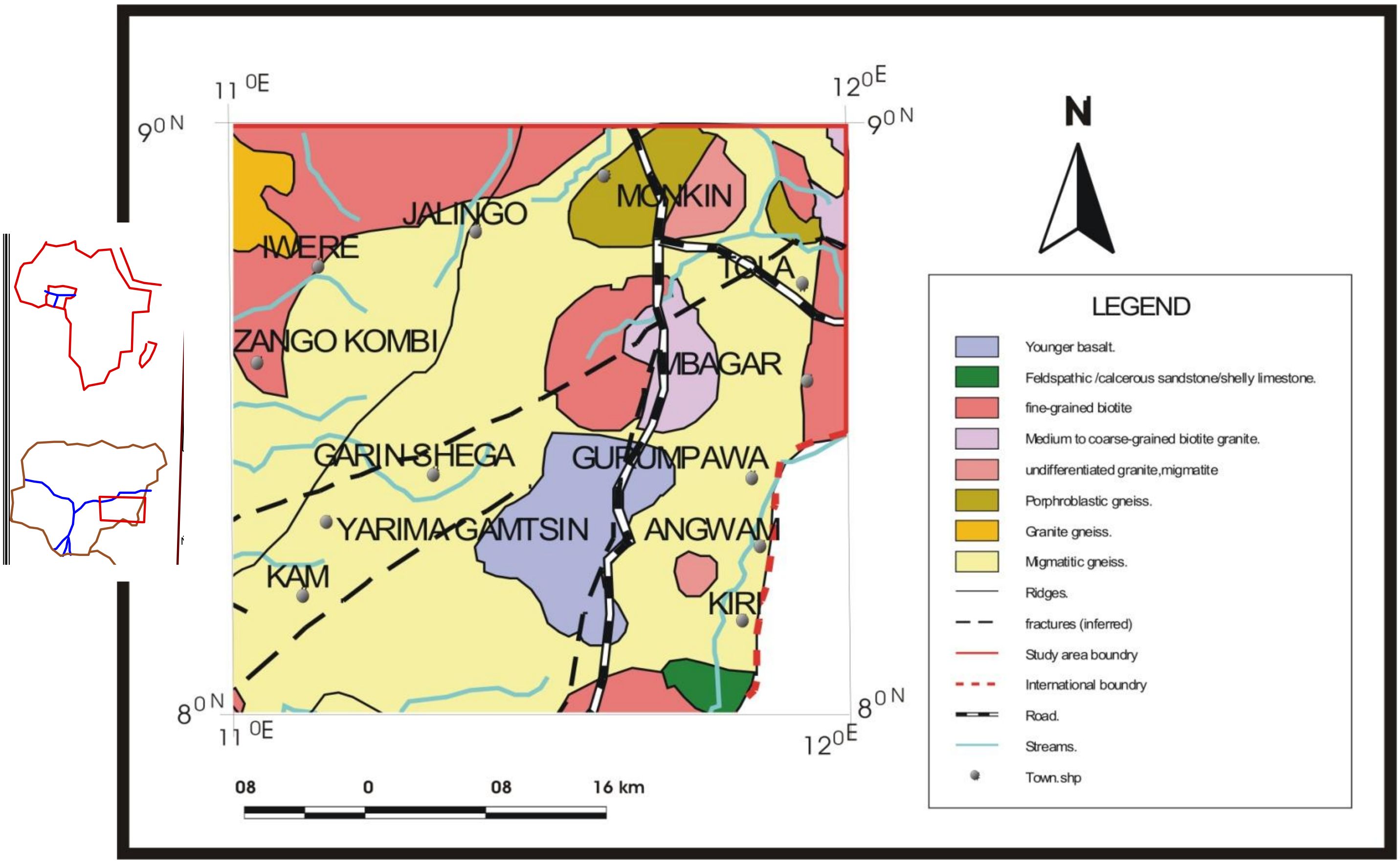

Fig.1. Geological map of study area (After GSN 2006)

Analysis of magnetic data

The aeromagnetic data which consist of sheet 215 and 216, 236 and 237 utilized for this paper was obtained as controlled maps of total magnetic intensity on a scale of 1:100,000 compiled by Geological survey of Nigeria (GSN 1975). The relevant survey was conducted along a series of SE- NW profile with a spacing of 2km, a nominal tie line spacing of 20Km and an average flight elevation above terrain of 150 m. The geomagnetic gradient was removed using the international Geomagnetic Reference field formula (IGRF) of the 1st January, 1974. The magnetic map was digitized at an equal interval of 2cm x 2 cm in the N-S and E-W grid lines giving a data matrix of (56 x 56). The points sampled on the square grid were contoured using a Computer software (surfer 8.0) and this represent the total intensity magnetic (Fig 2) below.

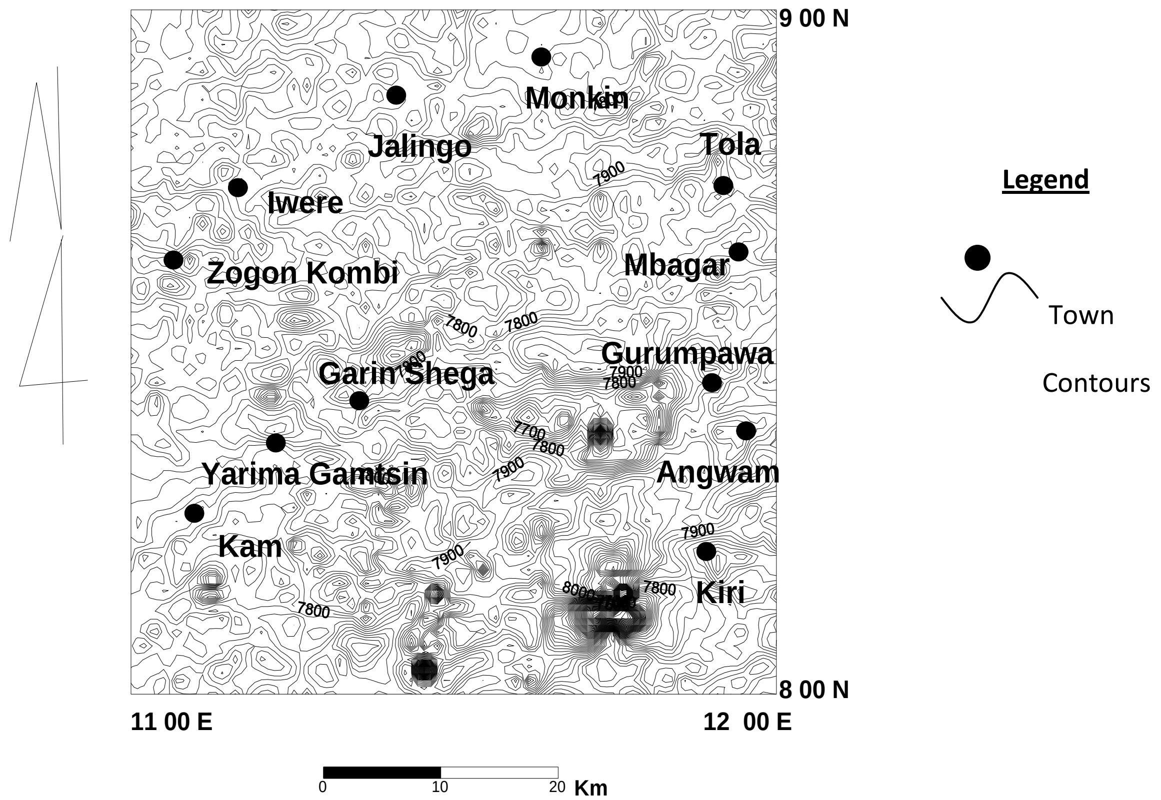

Fig.2. Total intensity Magnetic Map of the Study area(Contour interval 20 nT)

To remove the regional magnetic field which is the anomalies associated with low frequency components, a simple Computer program in visual basic was used to carry out the regional residual separation. This is to obtain the residual magnetic data of the study area (Fig 3)

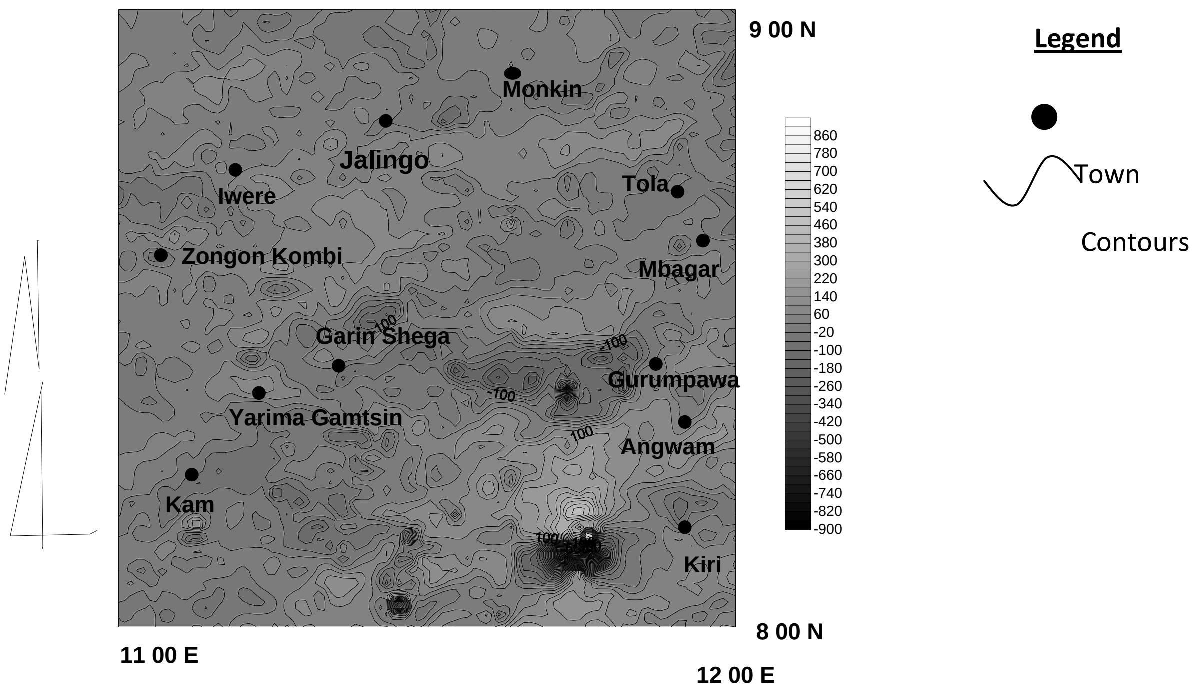

Fig.3.Residual Contour map of study area (contour interval 20nT)

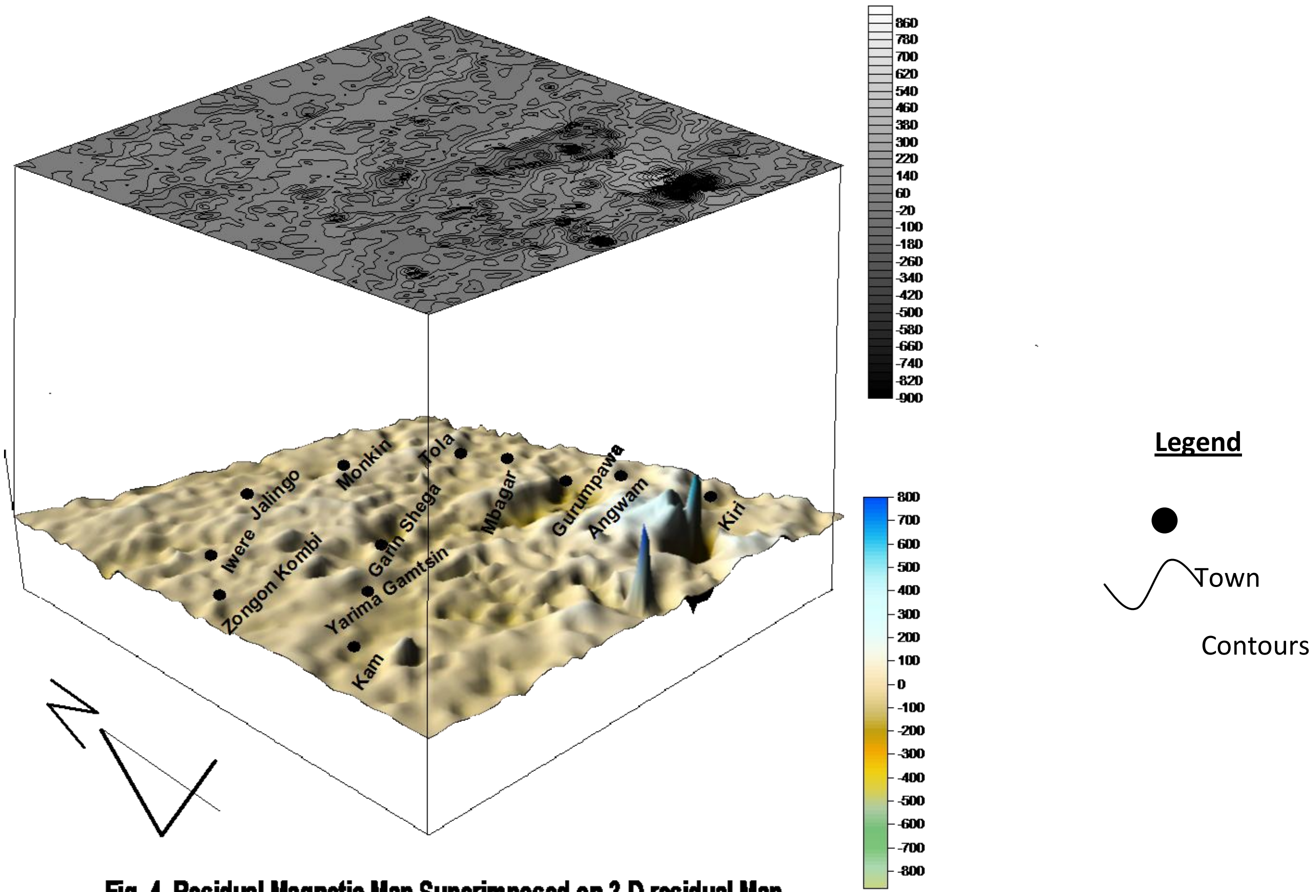

Fig. 4. Residual Magnetic Map Superimposed on 3-D residual Map

Curie point depth determination.

The methods for estimating the depth extent of magnetic sources are classified into two categories; those that examine the shape of isolated anomalies (Bhattacharyya and Leu 1975) and those that examine the patterns of the anomalies (Spector and Grant 1970). How ever both methods provides the relationship between the spectrum of the magnetic anomalies and the depth to magnetic sources by transforming the spatial data into frequency domain, In this paper the method adopted is the latter.

To carry out Spectral analysis, the residual data of the Study area was divided into sixteen (16) blocks containing (16 x16) data points. In doing this, it was ensured that no essential part of the anomaly was cut-off by the blocks. Since the objective of this paper is to determine the Curie depth isotherm and geothermal structure of the area from spectral analysis, each block was continued upward to eliminate shallow source and enhance the deep seated magnetic sources. The analysis was carried out using computer software FOURPOT, Version 1.0a Markku (2009).

The first step, is the depth to be estimated to the centroid (Z_o) of the magnetic source from the slope of the longest wavelength part of the spectrum,

$$\ln\left[\frac{p(s)^{1/2}}{/s/}\right] = \ln A - 2\pi /s/Z_o \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (1)$$

Where P(s) is the radially averaged power spectrum of the anomaly, /s/ is the wave number, and A is a constant.

The second step is the estimation of the depth to the top boundary (Z_t) of that distribution from the slope of the second longest wavelength spectral segment (Okubo et al 1985),

$$\ln\left[P(s)^{1/2}\right] = \ln B - 2\pi /s/Z_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where B, is the sum of constants independent of **/s/.**

Then the basal depth (Z_b) of the magnetic source was calculated from the equation below,

$Z_b = 2Z_o - Z_t$. ……………………… (3)

The obtained basal depth (Z_b**)** of a magnetic source is assumed to be the Curie point depth (Bhattacharyya and Leu (1975) and Okubo et al (1985) as shown on Table 1.

The knowledge of the depth to Curie point and its variation are of interest and can be related to the thermal history of the area. The interpretation of aeromagnetic data to estimate the depth to Curie points isotherm over Monkin and environs, will contribute to the better understanding of geothermal regime and tectonic activities in this area.

Estimation of Heat flow and thermal gradient

The heat flow and thermal gradient values was calculated to determine the thermal history of the crust in the study area. The calculation is expressed by Fourier's law with the following formula

$$q = \lambda \frac{dT}{dZ} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (4)$$

Where q is the heat flow and λ is the coefficient of thermal conductivity. In this equation, it is assumed that the direction of the temperature variation is vertical and the temperature gradient d_T/d_Z is constant. According to Tanaka *et al*. (1999), the Curie temperature (θ) was obtained from the Curie point depth (Z_b) and the thermal gradient dT/dZ using the following equation;

$$\theta = \left[\frac{dT}{dZ}\right] Z_b \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

In this equation according to Tanaka et al 199, it is assumed that the surface temperature is 0 °C and no heat sources exist between the Earth’s surface and the Curie point depth. In addition to that, from Equation (4) and Equation (5) a relationship can be determined between the Curie point depth (Z_b) and the heat flow (q) as follows.

$$q = \lambda\left[\frac{\theta}{Z_b}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

In this equation the Curie point depth is inversely proportional to the heat flow, Tanaka *et al*. 1999; Stampolidis *et al*.

2005). In this paper, the Curie point temperature of 580 °C was used (i.e. Curie temperature of magnetite)() in order to compute the thermal gradient of the region. Thus, the thermal gradient was calculated from Curie temperature of magnetite (580°C) /Curier depth isotherm value (°C/km). ; Stampolidis *et al*. 2005). To fix the heat flow value of the region, Equation (6) was used with thermal conductivity value (λ) of 2.1 Wm-1 °C $^{-1}$ Tanaka et al (1999).The results are shown on Table 1.Below.

Table1. Calculated Average Curie point depth and Heat flow from spectral analysis.

Blocks	Depth to Centroid (Z_o) km	Depth to Top bound(Z_t) km	Depth to curie point(Z_b) km	Geothermal gradient (ºC/km)	Heat flow (mWm^{-2})
1	3.619	0.209	7.029	82.51	173
2	3.225	0.375	6.025	96.266	202
3	0.934	0.143	1.725	336.23	706
4	1.457	0.317	1.806	321.15	674.4
5	1.850	0.487	3.213	180.52	379.1
6	1.490	0.508	2.472	234.63	492.72
7	1.450	0.174	2.726	212.77	446.81
8	2.697	0.405	4.989	116.26	244.14
9	0.971	0.174	1.769	327.87	688.51
10	1.098	0.397	1.799	322.40	677.04
11	1.044	0.136	1.952	297.13	624.00
12	1.079	0.321	1.837	315.73	663.03
13	2.779	0.940	4.618	125.60	263.75
14	3.703	0.609	6.797	85.33	179.2
15	5.299	0.822	9.776	59.33	125.00
16	1.342	0.178	2.506	231.00	486.03

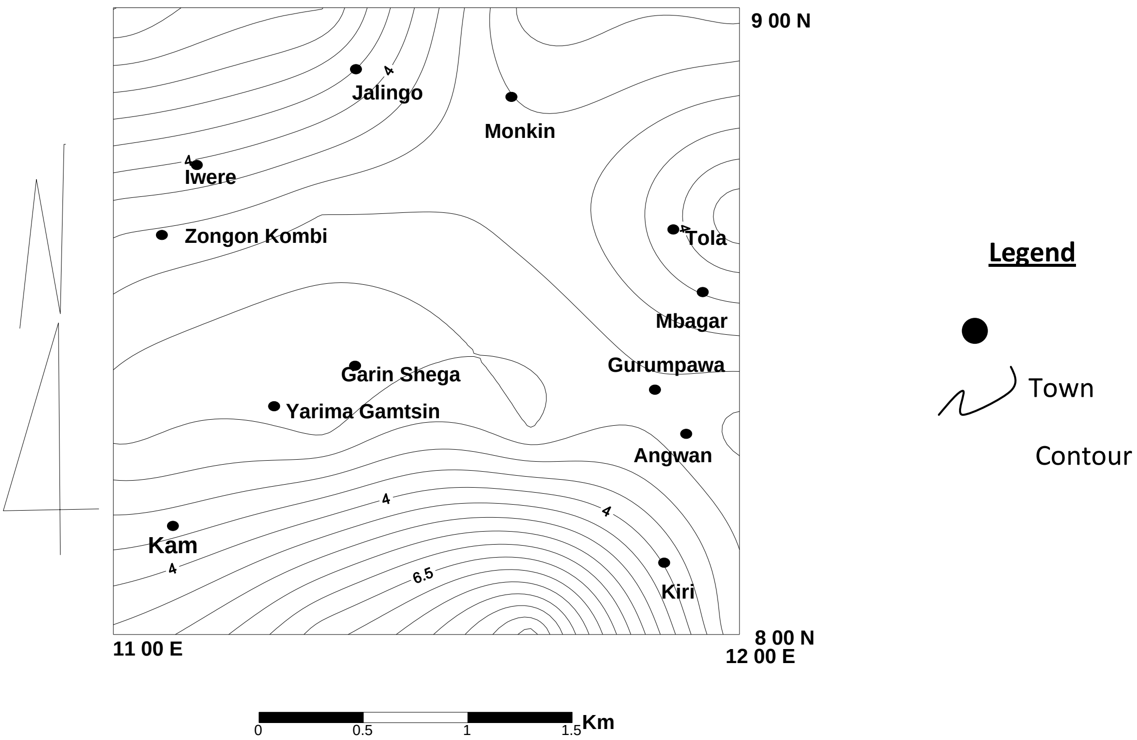

Fig.5. Curie depth Isotherm Surface of the Study area(Contour interval of 0.5 km)

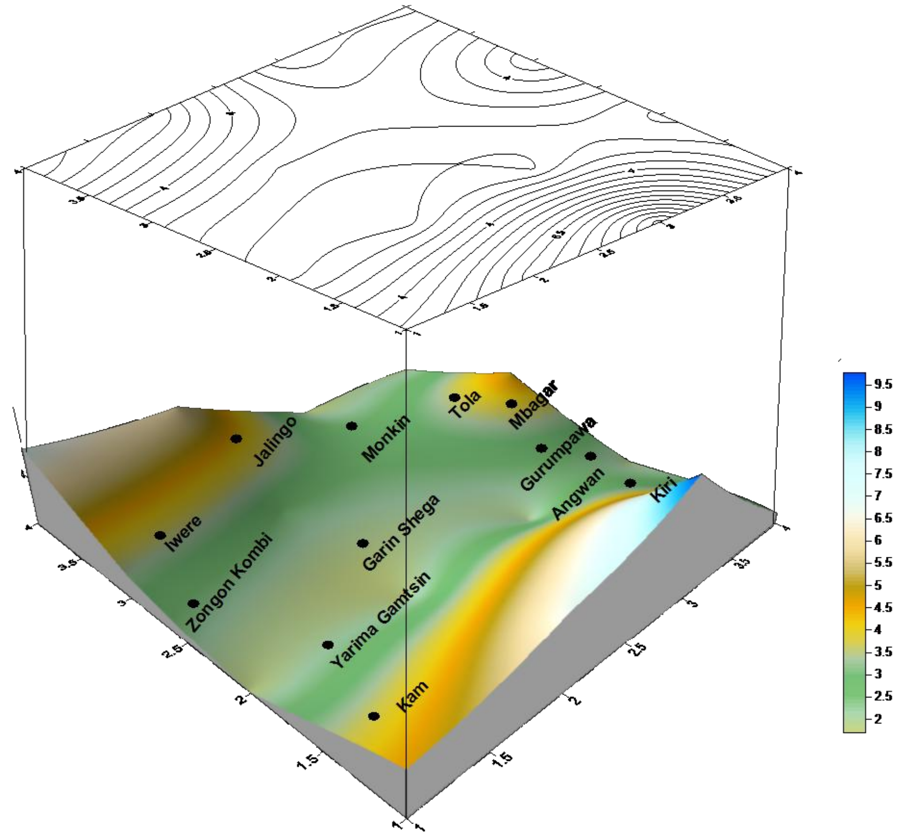

Fig. 6.Curie depth isotherm surface superimposed on 3-D

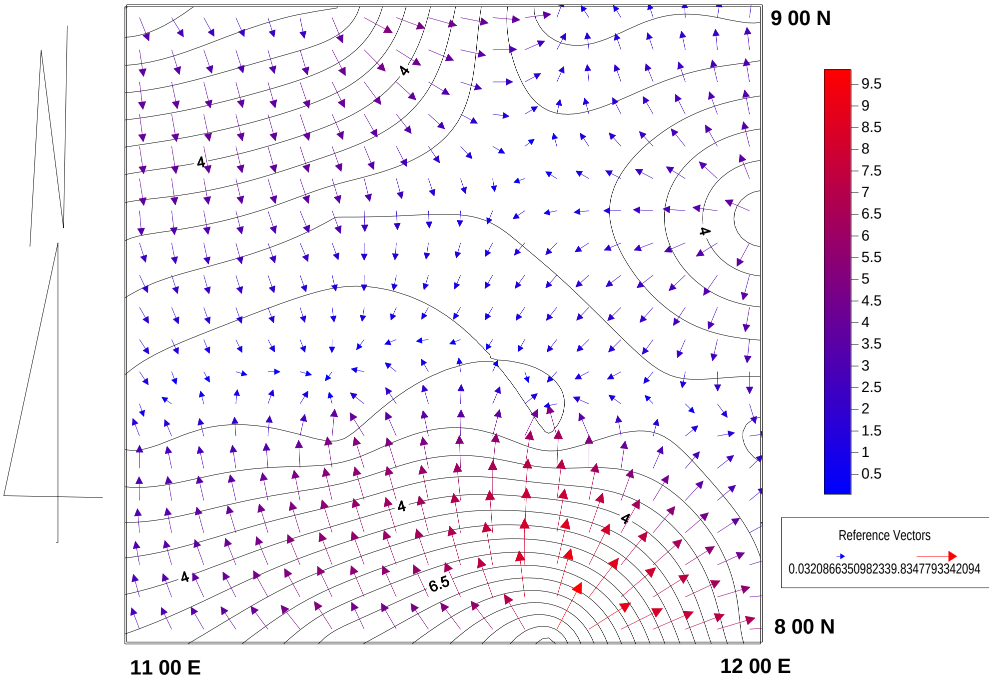

Fig.7.Curie depth isotherm surface Vector showing the direction of Heat flow in the study area

Discussion of Results

The residual magnetic anomaly map obtained from regional – residual separation (Fig.3) have widespread of closures and nosing, these closures and nosing's are expression of fractures and volcanic arcs of tectonically active Cameroon volcanic line as shown on the 3-D residual magnetic map on which the residual map was superimposed (Fig.3 and 4). The result of the spectral analysis of upward continued data (altitude of 8km) for each block, from which the Curie isotherm depth was computed, showed that the depth to the centroid (Z_o) ranges from 0.900 km to 5.3 km on the other hand, the depth to the top bound (Z_t) of magnetic sources ranges from 0.30 km to 0.40 km (below sea level) Table 1. The equivalent curie depth ranges from 1.720 km to 9.8 km (b.s.l). The obtained Curie point depth reflects the average local curie depth point values beneath each block. Previous studies by Nafiz (2009) showed that the Curie point depth is linked to the geological context of an area. The values obtained falls in class A classification of Tanaka et al (1999), in which he suggest that, shallow Curie point depth values ≤ 12km have possible geothermal potential. He also pointed out that that the Curie point depth are about 10 km or less in volcanic and geothermal areas, 15-25km on Island arcs and ridges and deeper than 20km in plateau and over 30km in trenches, Yamano (1995) made an assertion that the shallow Curie point depths are consistent with high heat flow values as seen in back arc, and young volcanic regions.

It is also worth noting that the Curie depth point values in study area, reveals an interesting subsurface features for geothermal exploration. This is clearly shown on (Fig.5), which indicate the Curie depth isotherm, and (Fig.6), which shows the Curie depth isotherm superimposed on 3-dimension. These indicate that areas around Kam, west of Kiri, Tola, north of Iwere and Jalingo have deeper curie depth points and on the other hand around Zongon Kombi, Garin Shega, Mbagar, Gurumpawa , and Angwan have shallow depths. In that regard the vector map on (Fig.7) shows the direction of heat flow (from deep to shallow) in the study area.

The two components of the vector map (direction and magnitude) were automatically generated from the single grid by numerically, computing the gradient of the represented surface(Fig.7). This implies that the heat flow in the study area are not uniform which is possibly indicates that the magma conduits were randomly distributed.

The average heat flow obtained in the study area is 319 mWm^{-2}, the high heat flow in this area resulted from tectonically active Cameroon Volcanic line (CVL) where the most recent eruption being in March/April 1999 (ghongonmu et al., 1999). This may be economically good alternative source for geothermal reservoir exploration for energy in the southern part of the study area.

CONCLUSION.

The Curie point depth for the study area was estimated using surface magnetic data through spectral analysis. The result reveals that, the Curie depth point varies considerably. The inferred Curie point depth obtained ranges from 1.720 km to 9.8 km. These are rather shallow depths which suggest a high heat flow.This result also confirms that Curie depths are indirect indicator of the thermal structure of the area. The average heat flow obtained is 319 mWm^{-2}. The most plausible mechanism responsible for the high heat flow is tectonically induced magmatism of Cameroon volcanic line.It might be possible that partial melting of the crust caused by rising magma contributed to the present high geothermal potential which can be good sources for geothermal reservoir exploration for alternative source of energy especially in the southern part of the study area .

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