Interpretation of High Resolution Aeromagnetic Data to Estimate the Curie Point Depth Isotherm of Parts of Middle Benue Trough, North-East, Nigeria

By

Adewumi Taiwo

Department of Physics, Federal University Lafia,

Nasarawa State.

*Presentation at Nigerian Association of Petroleum Explorationists Workshop titled"**Cretaceous Basins in Nigeria"** at the Nigerian Air Force Conference Center, Abuja, Nigeria, 5th May, 2019.

CONTENTS:

Introduction

- This paper presents the result of Curie point depth (CPD) from spectral analysis of aeromagnetic data over part of middle Benue trough, NE, Nigeria.

- The bottom of a magnetic source indicate the thermal boundary at which magnetic mineral in the crust lose their magnetic properties as a result of increase in temperature as depth increase down the crust.

- This Curie point has a Temperature 0f 5500C± 300C. For temperature above curie-point, magnetic materials loose there magnetic ordering and both induced and remnant magnetisation disappears, and for temperature greater than 580°C those materials will begin to encounter ductile deformation.

Introduction Cont'd …

- Previous studies have shown that spectral analytical method can be regarded as a proxy for an estimate of Curie-point depth(CPD). Records have also shown that there is minimal record of geophysical studies on regional geothermal structure in the middle Benue trough.

- In an effort to boost the power sector of Nigeria, this research work was carried out with the aim of estimating the Curie point depth isotherm of part of middle Benue trough using high resolution aeromagnetic data for geothermal potential source.

LOCATION AND GEOLOGY OF THE STUDY AREA

Location of the Study Area

The study area (Part of Middle Benue Trough) is located in the northeastern part of Nigeria and lying between Latitude 8°0'N and 9°30'N and longitudes 9°0'E and 10°0'E with estimated total area of *18,150km²*.

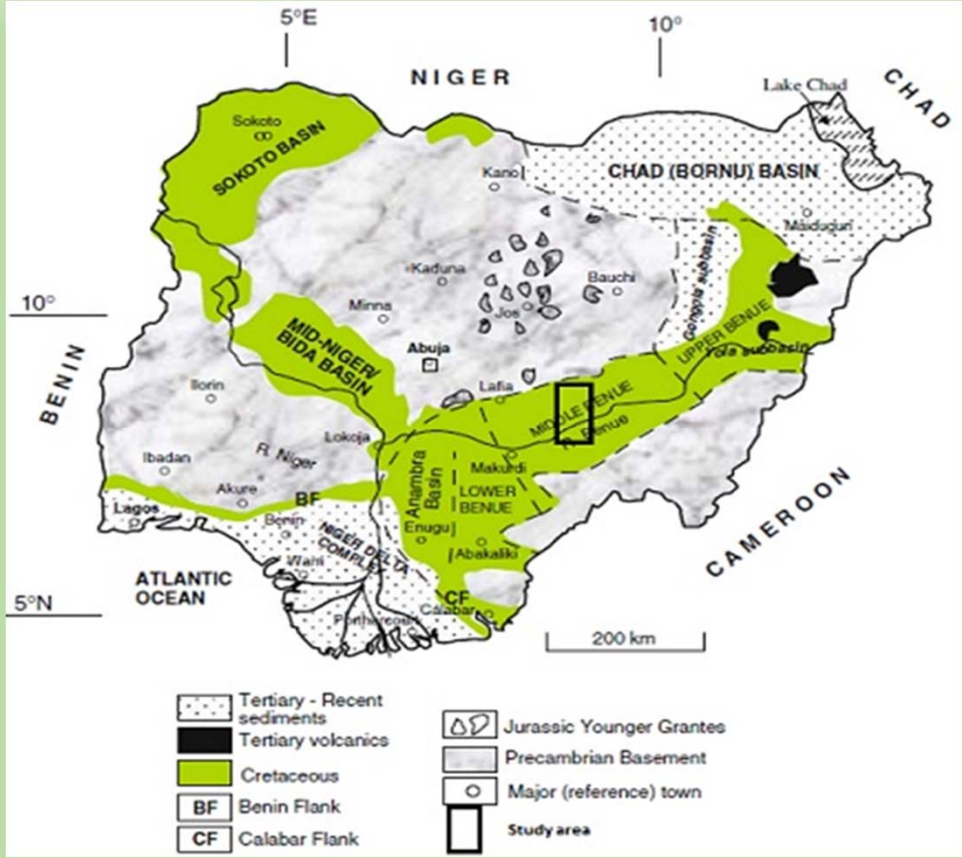


Fig.1 Geological Map of Nigeria showing the study area in black outlined (Modified after Obaje, 2009)

Geology of the study Area

The Benue Trough comprises of a progression of rift basins that model a portion of the Central West African Rift System of the Niger, Cameroon, Chad and Benin Basement fracture, subsidence, block faulting and cracking.

Benkhelil (1982 and 1989), pointed out that the Benue Trough generally has been geographically and structurally subdivided into three parts erroneously termed as "lower Benue Trough", "middle Benue Trough" and an "Upper Benue Trough".

The study conducted by Offodile (1976) distinguishes six sedimentary Formations in the middle Benue trough which are Asu River Group, Keana Formation, Awe Formation, Ezeaku Formation, Awgu Formation and Lafia Formation.

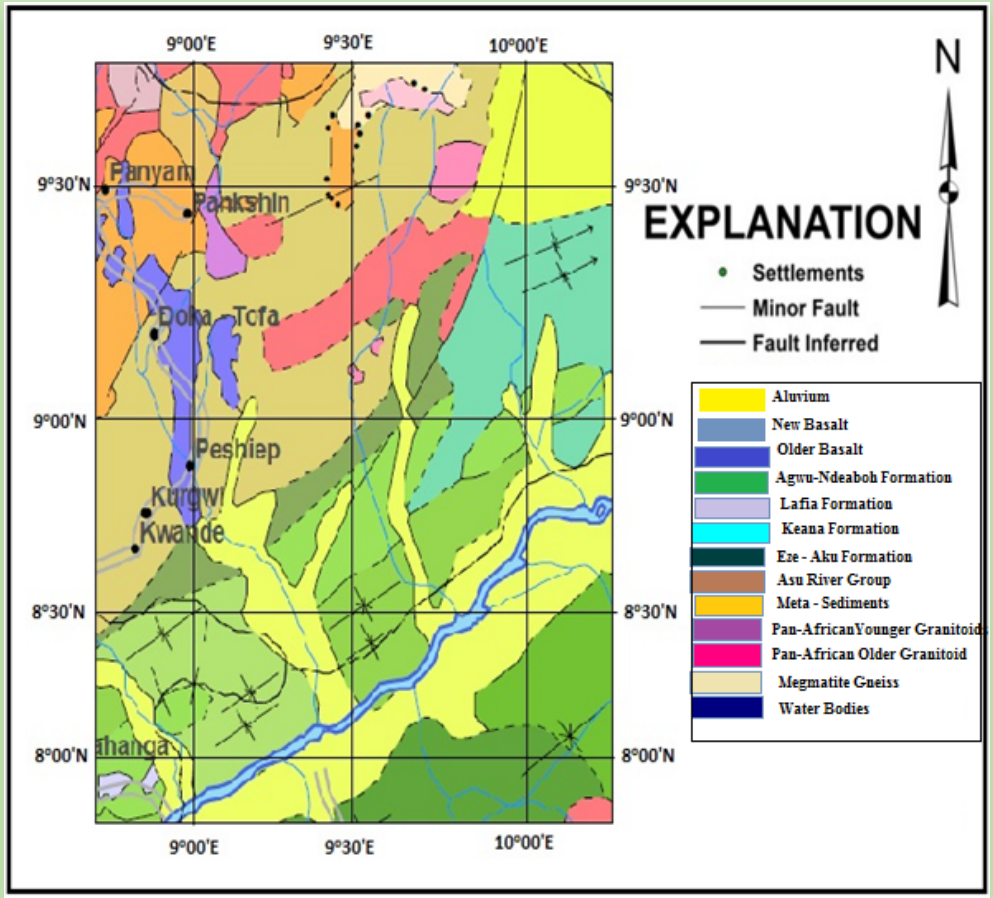


Fig.2 Geological map of the middle Benue trough (Extracted from Geological Map of Nigeria, NGSA (2006))

Methodology

Materials

- Data – Airborne Magnetic data
- Software – Oasis Montaj

Data Acquisition

The high resolution aeromagnetic data used for the analysis of this study were part of the data collected from the airborne magnetic survey carried out in the year 2009 by Fugro. The collections of the data were sponsored by Nigerian Geological Survey Agency. Below are the technical details of the survey/ flight parameters:

Flight line spacing: 500 m

Terrain clearance: 100 m

Flight direction: NW - SE

Tie lines spacing: 2 km

Tie line direction: NE - SW

Methodology Cont'd…

Methods

- Assembling and knitting of the six sheets of the aeromagnetic data to produce the composite map (TMI) of the study area.
- Regional/residual separation on the Total magnetic intensity map (TMI)
- Division of the residual map into 16 overlapping blocks for spectral analysis.
- Plotting of log of power spectrum against wavenumber to determine the centroid depth and depth to top of basement.
- Curie point depth calculated using; $Zb = 2Zo - Zt$.

Spectral Analysis

Theory of Methods

- This study used the spectral analysis of the aeromagnetic data to determine the CPD of the study area.
- Spector and Grant (1970) explained the spectral analysis method which was used to determine the depth to top of magnetic four-sided prism (Z_t) from the gradient of the log of power spectrum.
- The depth to centroid of the magnetized source rock (Z_o) was calculated by Bhattacharyya and Leu (1975, 1977) from the idea of Spector and Grant (1970).
- Okubo et al. (1985) combined and expanded the idea from Spector and Grant; Bhattacharyya and Leu to develop the method to determine the bottom depth of magnetized bodies (Z_b).

Curie Point Depth Estimation

❖ According to Okubo *et al*. (1985), CPD (Z_b) can be achieved in two stages;

➢ First of all, the centroid depth (Z_0) of the inmost magnetic source is appraised from the gradient of the lengthiest wavelength part of the spectrum divided by the wave number using the following equation (Nwankwo and Shehu 2015):

$$In\left(\frac{P(k)^{1/2}}{k}\right) = A|k|Z_o$$

where P(k) is the power density spectrum, k is the wavenumber, Zo is the centroid depth and A represents a constant.

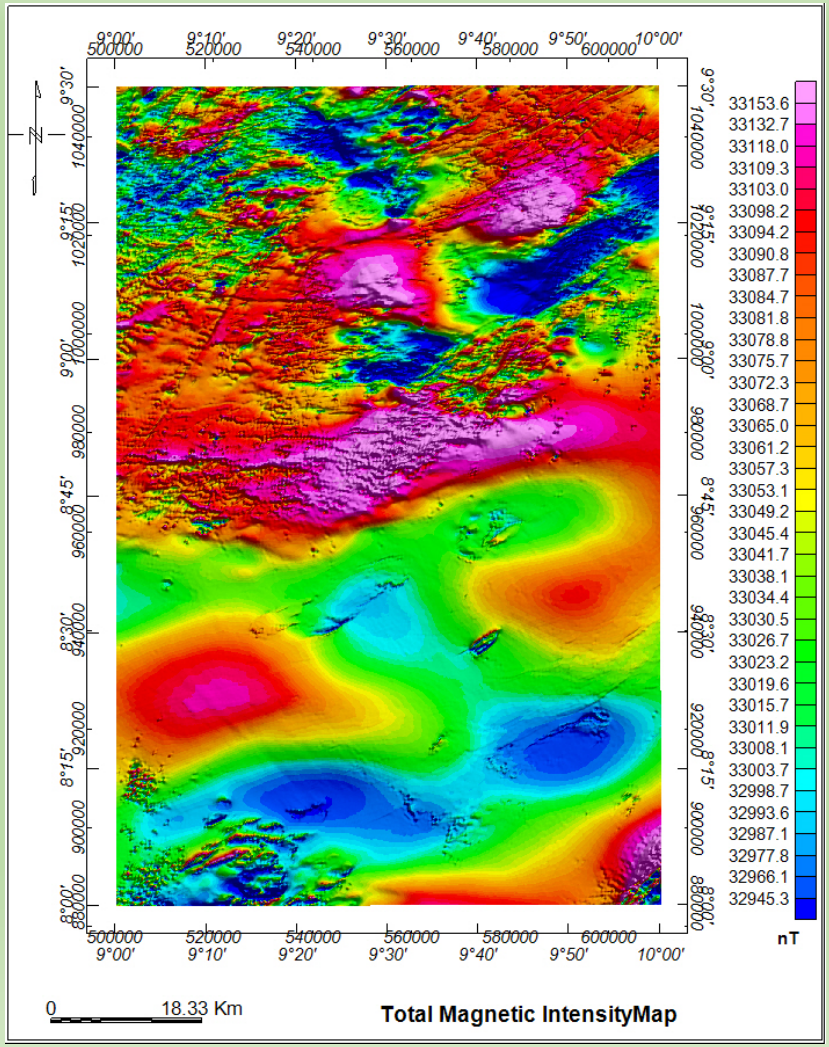
➢ Secondly, the uppermost depth to magnetic body is also derived from the gradient of high wave number portion of the power spectrum as follows

$$In\left(P(k)^{1/2}\right) - B - |k|Z_t$$

where P(k) is the power density spectrum, k is the wavenumber, Zt is the top depth and B represents a constant.

Results and Discussion

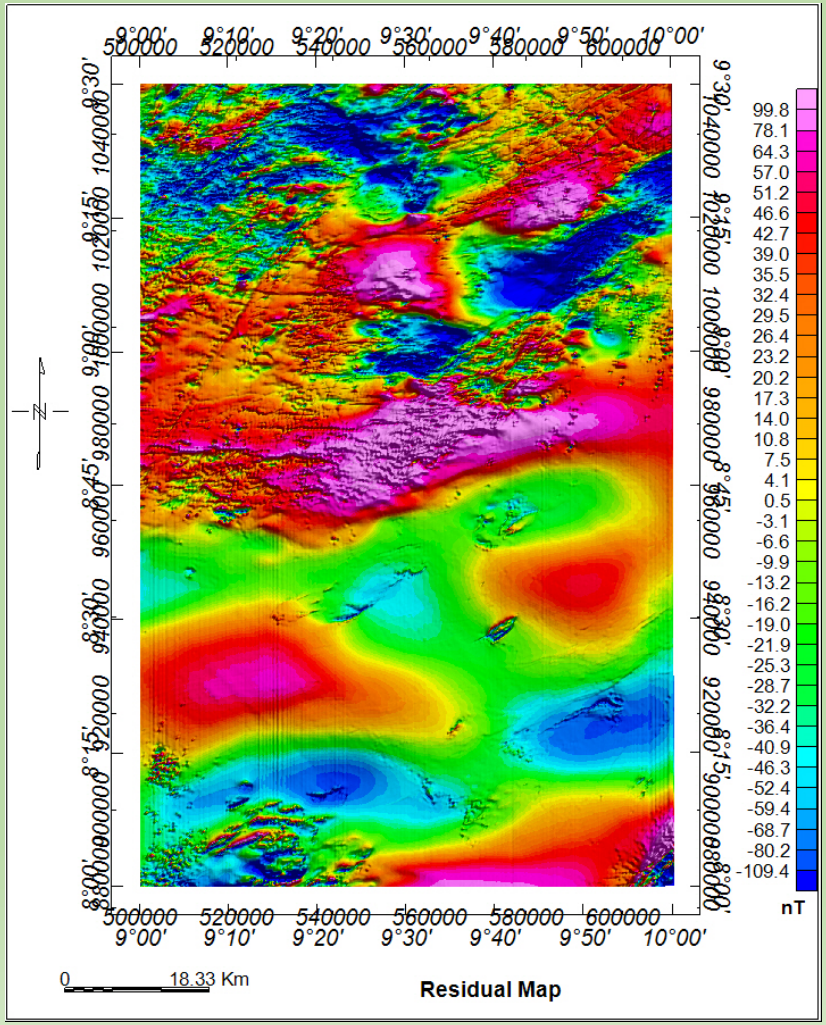
Fig. 3: Total Magnetic Intensity Map



The total magnetic intensity map, TMI (Fig. 3) shows variation of highs and lows in magnetic signature. About one third of the map can be seen to be greenish (featureless) which may correspond to alluvium deposition in the southern part of the study area, the pink colouration depicts high magnetic signature while blue depicts low magnetic signature and yellow indicates intermediary.

Results and Discussion Cont'd….

Fig. 4: Residual Map of the study area



The residual of the magnetic intensity map (Fig. 4) also shows variation of highs and lows in magnetic signature. The negative values imply areas that are magnetically subdued or quiet while the positive values are magnetically responsive. The magnetically subdued areas are the magnetic lows of the study area and this is typical of a sedimentary terrain while the magnetic responsive areas are the magnetic highs regions which are assumed to be due to the likely presence of outcrops of crystalline igneous or metamorphic rocks, deep seated volcanic rocks or even crustal boundaries.

Results and Discussion Cont'd….

Result of Spectral Analysis

- The residual map (Fig. 4) of the study area was divided into fourteen (Blocks A - N) overlapping magnetic sections.
- In which six (Blocks A - F) covered 55 km by 55 km data points, three other division (Block G,H and I) covered 110 km by 55 km data points, J, K and L covered 110 km by 110 km and Block M and N covered the remaining 165 km by 55 km part of the study area.
- The divisions of residual map into spectral sections or blocks were done with Oasis Montaj.
- The analysis was carried out using a spectral program plot (SPP) developed with MATLAB. Graph of the logarithm of spectral energies against frequencies obtained for blocks A, B, C and D.

Results and Discussion Cont'd….

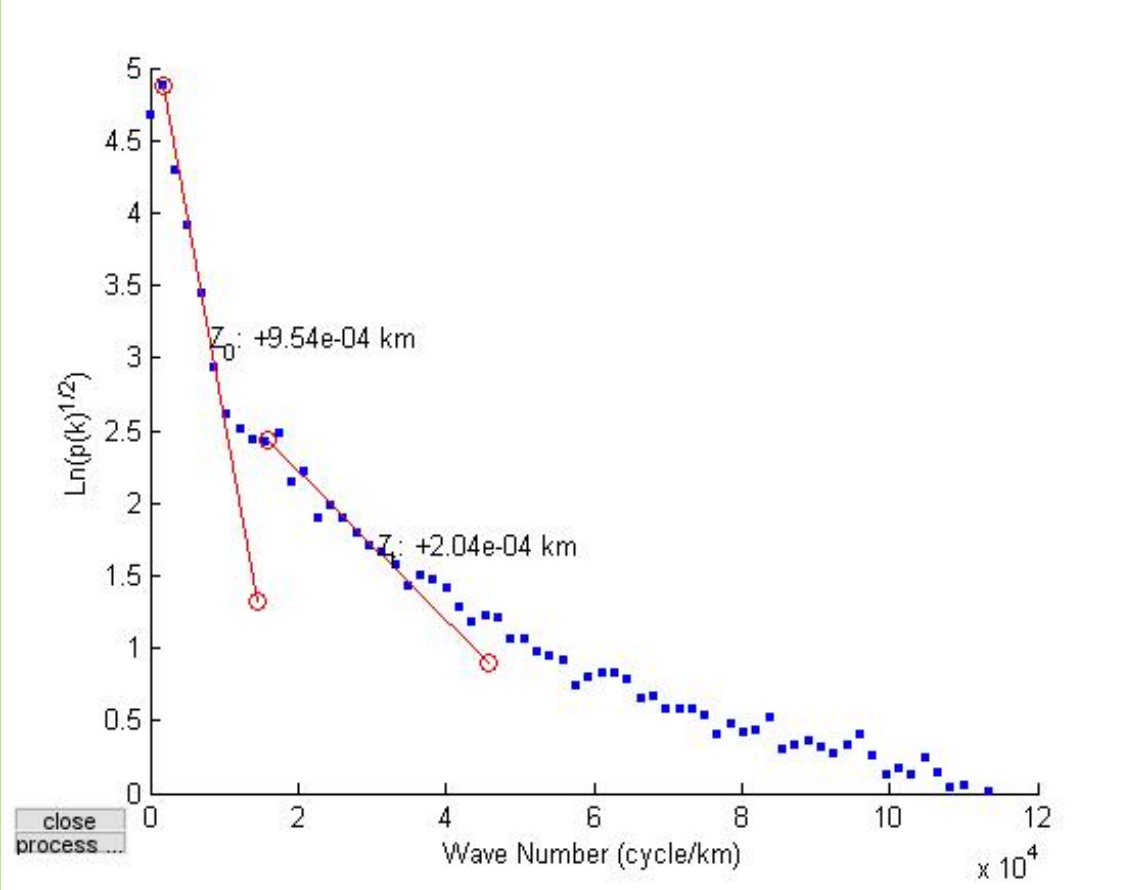


Fig. 5 Typical plots of the logarithm of spectral energies against frequencies obtained for block A

Results and Discussion Cont'd….

Table 1. Location and depth estimation of centroid depth (Z0), depth to basement (Zt) and CPD (Zb)

Blocks	Longitude (degree)	Latitude (degree)	Depth to centroid, Z_o(km)	Depth to the top boundary Z_t(km)	Curie-point depth, Z_b(km)
A	9.25	9.25	9.54	2.04	17.04
B	9.75	9.25	13.30	2.50	24.1
C	9.25	8.75	11.40	2.14	20.66
D	9.75	8.75	10.82	1.98	19.66
E	9.25	8.25	9.56	1.20	17.92
F	9.75	8.25	9.36	1.40	17.32
G	9.5	9.25	10.60	2.00	19.20
H	9.5	8.75	15.40	3.20	27.40
I	9.5	8.25	10.44	1.70	19.18
J	9.5	9.0	11.04	1.50	20.58
K	9.5	8.0	12.98	1.84	24.12
L	9.25	8.25	14.70	2.08	27.32
M	9.75	8.25	11.32	1.86	20.78
N	9.5	8.25	12.42	1.65	23.19
Average			11.63 km	1.94 km	21.32 km

Results and Discussion Cont'd….

Curie point Depth (CPD)

- The results of the spectral analysis of aeromagnetic anomalies over the area shows that the depth to top of magnetic basement also know as sedimentary thickness ranges from 1.0 km to 3.20 km, the centroid depth ranges from 9.36 km to 12. 98 km and the Curie point depth estimates (using Zb = 2Zo - Zt) range between 17.04km and 27.4km (Table 1) with an average value of 21.32 km.

- 3D surface map of the depth to top (Fig. 6) reveal a maximum depth of 3. 1 km at the central part of the study area which corresponds to part of Shendam while shallow depth at the southwestern part of the study area which also corresponds to Akiri and Akwana. This shallow depth might be as a result of igneous intrusion or the dominance of Ezeaku formation (sandstone and lime stone) in the area.

- Fig. 7 (3D surface map of Centroid depth) reveal a deeper depth at the central part of the study area while shallow depth at to the north-western, southeastern and southwestern part of the study area.

Results and Discussion Cont'd….

- The 3D surface map of the CPD (Fig. 8) reveal a maximum depth of 27 km at the central towards the North-eastern part of the study area which corresponds to Shendam and Wasa while shallow at the north-western that corresponds to Pankshin, Part of western and eastern part of the study area which corresponds to Akiri and Ibi respectively.

- Previous researches across the globe have shown that CPD shallower than 10 km are associated with volcanic, tectonic and geodynamic environments, while CPDs ranging from 15 km to 25 km is also associated with Island arcs and ridges and CPDs deeper than 25 km occurs in Plateaus and trenches.

Results and Discussion Cont'd….

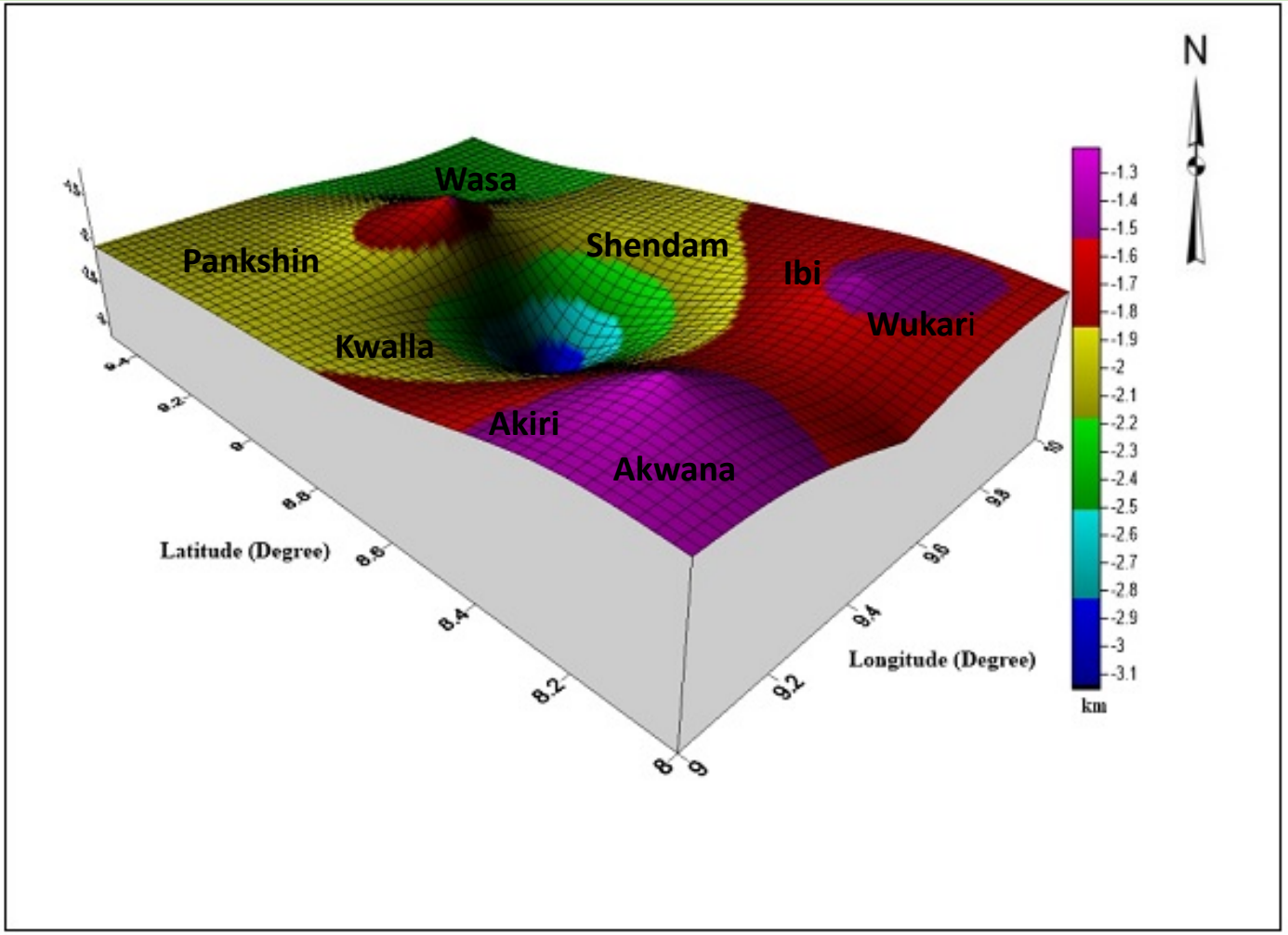


Fig. 6: 3D Surface map of the Depth to top of magnetic Basement

Results and Discussion Cont'd….

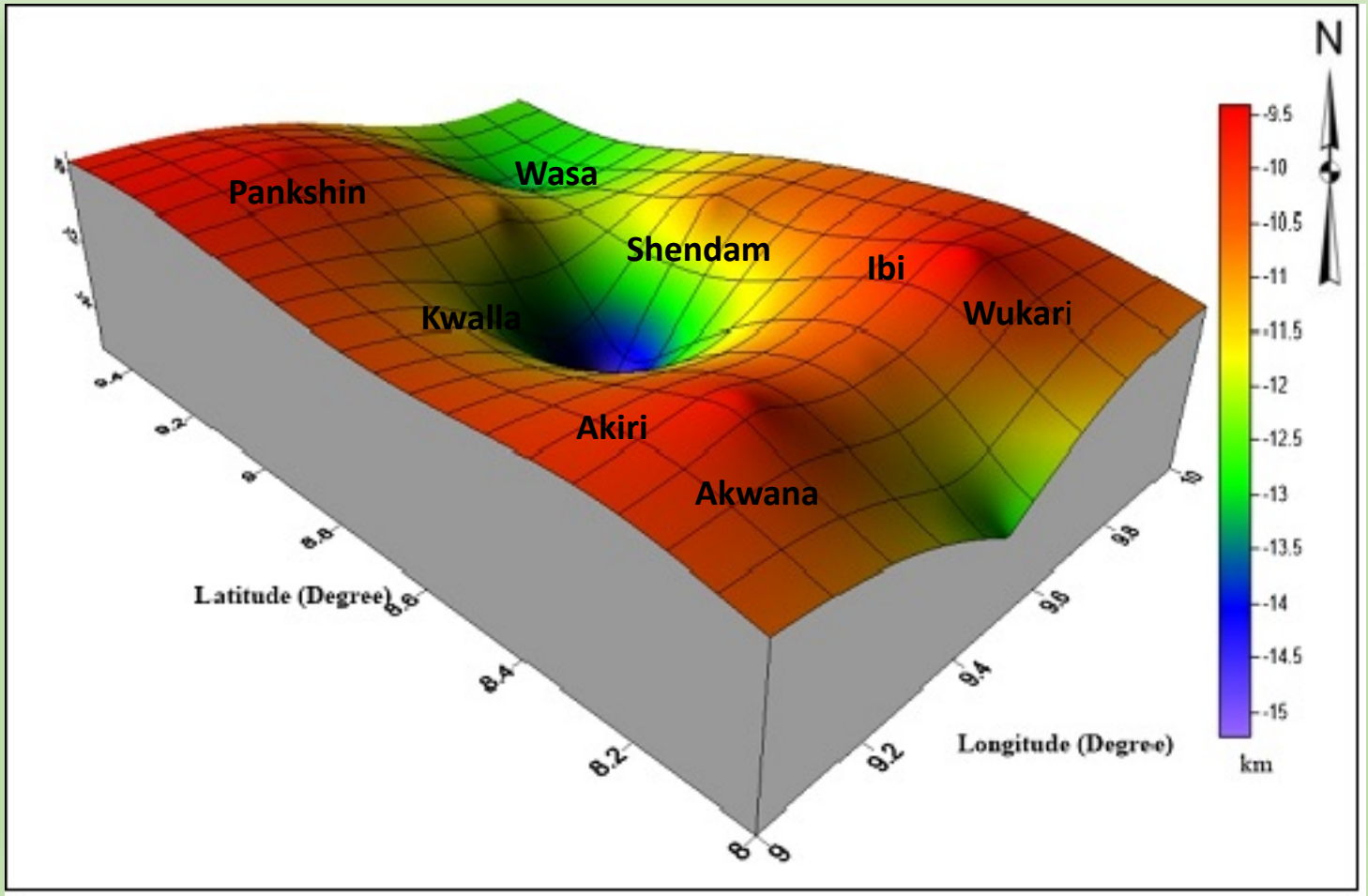


Fig. 7: 3D Surface map of the Centroid Depth

Results and Discussion Cont'd….

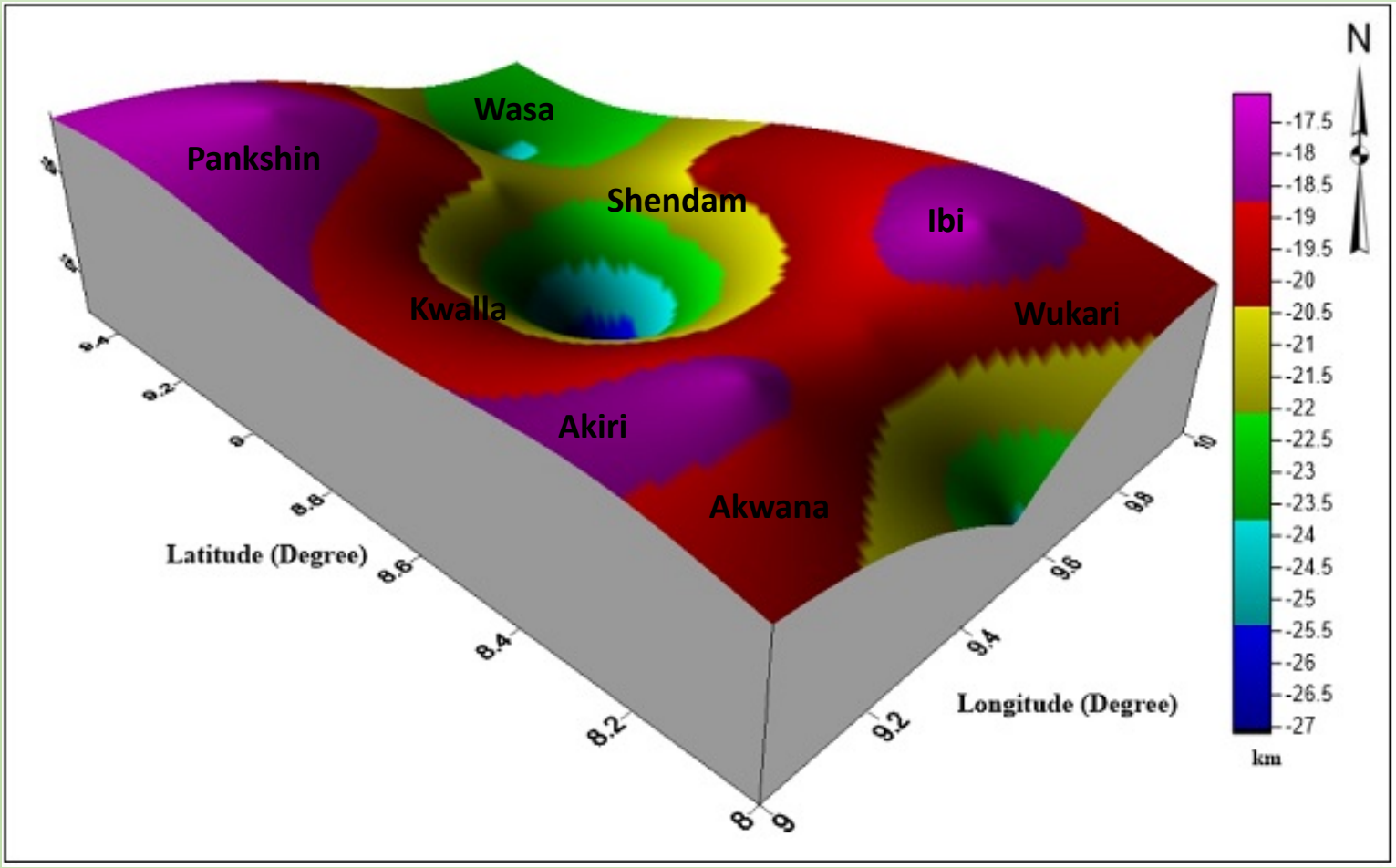


Fig. 8: 3D Surface map of the Curie point Depth

Conclusion

- The aeromagnetic data of part of middle Benue has been interpreted quantitatively to estimate the CPD for geothermal energy potential.
- Result from the spectral analysis have shown a maximum depth of 27 km at the central towards the North-eastern part of the study area which corresponds to Shendam and Wase while shallow at the north-western that corresponds to Pankshin, Part of western and eastern part of the study area which corresponds to Akiri and Ibi respectively.
- Researches conducted across the globe have shown that CPD shallower than 10 km are associated with volcanic, tectonic and geodynamic environments, while CPDs ranging from 15 km to 25 km is also associated with Island arcs and ridges and CPDs deeper than 25 km occurs in Plateaus and trenches.
- It can therefore be inferred from the statement above that CPD shallower than 10 km and deeper than 20 km are not good source of geothermal energy.

Conclusion Contd..

- It can be concluded that the NW, W, SW, and SE part of the study area with shallow CPD ranging from 17.5 km and 20 km which corresponds to Pankshin, Akiri and Kwalla, Ibi and Wukari respectively are good source for geothermal energy.

- Energy is one of the fundamental necessities for economy growth, increased social quality and an environment that allows livelihoods to thrive (Ram Avatar and Pankaj Kumar, 2016).

THANK YOU FOR LISTENING……

Other Research Memebers: Salako K.A (Assc. Prof.), Aliyu A. and Mohammed A.

Nigerian Association of Petroleum Explorationists (NAPE)

Federal University Lafia, Nasarawa State

References

Bhattacharyya, B.K., Leu, L.-K., 1975. Analysis of magnetic anomalies over Yellowstone National Park: mapping of Curie point isothermal surface for geothermal reconnaissance. Journal of Geophysical Research. 80, 4461–4465

Obaje, N.G. (2009). Geology and Mineral Resources of Ni- geria. Lecture Notes in Earth Sciences. Eds.: Bhattacharji, S., Neugebauer, H.J, Reitner, J.,andStuwe, K. pub. Springer.

Offodile, M.E.(1976). The Geology of the Middle Benue Nigeria. Cretaceous Research, Paleontological Institute: University of Uppsala. Special Publication. 4:1-166.

Offodile, M.E. 1984. "The Geology and Tectonics of Awe Brine Field". *Journal of Earth Sciences*. 2:191-202.

Ofoegbu C. O. (1985). A review of the geology of the Benue trough, Nigeria. *Journal African Earth Sciences*pp 283 291

Okubo Y, Graf RJ, Hansen RO, Ogawa K, Tsu H (1985) Curie point depths of the Island of Kyushu and surrounding areas, Japan. *Geophysics* 53(3):481–494

Nwankwo, L.I., and Shehu, A.T. (2015). Evaluation of Curie-point depths, geothermal gradients and near-surface heat flow from high-resolution aeromagnetic (HRAM) data of the entire Sokoto Basin, Nigeria. Journal of Volcanology and Geothermal Research 305: 45–55.