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Research Paper

Estimation of Magnetic Basement Depth and Structure over parts of Bida Basin Nigeria using Aeromagnetic Data

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***ABSTRACT**: The Estimation of Magnetic Basement depth and Structures over parts of Bida using Aeromagnetic data was carried out in this study. The study area is between Latitudes 8.5^{o}N and 9.5^{o}N and Longitudes 5.5^{o}E and 6.5^{o}E which is represented by four aeromagnetic maps in 16 overlapping blocks involving towns like; Pateji, Baro, Bida and Agbaje. Several data enhancement techniques were carried out namely; reduction to pole, regional-residual separation, and shaded relief correction. Depth Estimations were made using Spectral Analysis and results of the 2D analysis revealed a two layer depth model with depth to the shallow magnetic bodies (D1) varying from 0.138km to 0.935km with an average depth of 0.583km while the deeper magnetic depth (D2) varies from 0.742km to 3.985km with an average depth of 2.983km. Structural analysis of the anomalies using 3D Euler Deconvolution and Structural index values ranging from 0 – 3 revealed three main structural features- Spheres, Pipes/cylinder and Sills/Dykes.*

***KEYWORDS:** Aeromagnetic data, Euler Deconvolution, Lithofacies, Reduction to pole, Spectral Analysis,*

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I. INTRODUCTION

The use of aeromagnetic data has found much significance in the study of geological structures. Several studies carried out worldwide ([1]; [2]; [3]; [4], among others) revealed that the use of aeromagnetic data added significant structural elements that were previously unrecognized from other interpretations of the dataset. Basically, aeromagnetic maps display variations in the magnetic field of crustal rocks and are usually expressed in gammas. This data can be used to delineate structural trends by following lineaments in magnetic contours [5]. They can also be used for depth-to- magnetic basement determination and to carry out preliminary mineral/hydrocarbon exploration of the study area.

Similarly, Magnetic method has a great deal for geological interpretation that can be established from it. It is extensively used as reconnaissance too in oil exploration, mineral exploration as well as in deep crustal studies. Magnetic basement is an assemblage of rocks that underlies sedimentary basins and may also outcrop in places. If the magnetic units in the basement occur at the basement surface, then depth determinations for this will map the basin floor morphology and its structure. The methods of magnetic depth estimation for this study are Spectral methods and the 3D Euler Deconvolution method.

Spectral method is very reliable for basement depth determination. Its operations are carried out in frequency domain [6]. The method is therefore well established in its use in inferring depth to magnetic sources ([7]; [8]). 3D Euler Deconvolution helps to produce a map showing the locations and the corresponding depth estimations of geologic sources of magnetic or gravimetric anomalies in a two- dimensional grid [9] and [10]. It is used for estimating the depth as well as locations of anomalous magnetic bodies and for locating/ inferring depths to subsurface geologic structures which gives rise to magnetic anomalies [11].

Previous studies on the analysis of aeromagnetic data have been carried out in Bida Basin by [12], [13], and [14]. Different analysis over parts of Bida Basin showed two depth source models in the areas: the deeper source and the shallower source. The Bida Basin (Mid-Niger basin or Nupe Basin) is located within the West Central Nigeria [15]. It is also a NW-SE trending structure extending from slightly south of Kontagora in Niger state in the north to the area slightly beyond Lokoja (Kogi state) in the south [16].

GEOLOGY OF THE STUDY AREA

The Mid-Niger Basin otherwise known as the Bida Basin or the Nupe Basin is a NW–SE trending intracratonic sedimentary basin extending from Kontagora in Niger State of Nigeria to areas slightly beyond Lokoja in the south (fig. 1). It is delimited in the northeast and southwest by the basement complex while it merges with Anambra and Sokoto basins in sedimentary fill comprising post orogenic molasse facies and a few thin unfolded marine sediments [16]. The basin is a gently down warped trough whose genesis may be closely connected with the Santonian orogenic movements of southeastern Nigeria and the Benue valley, nearby.

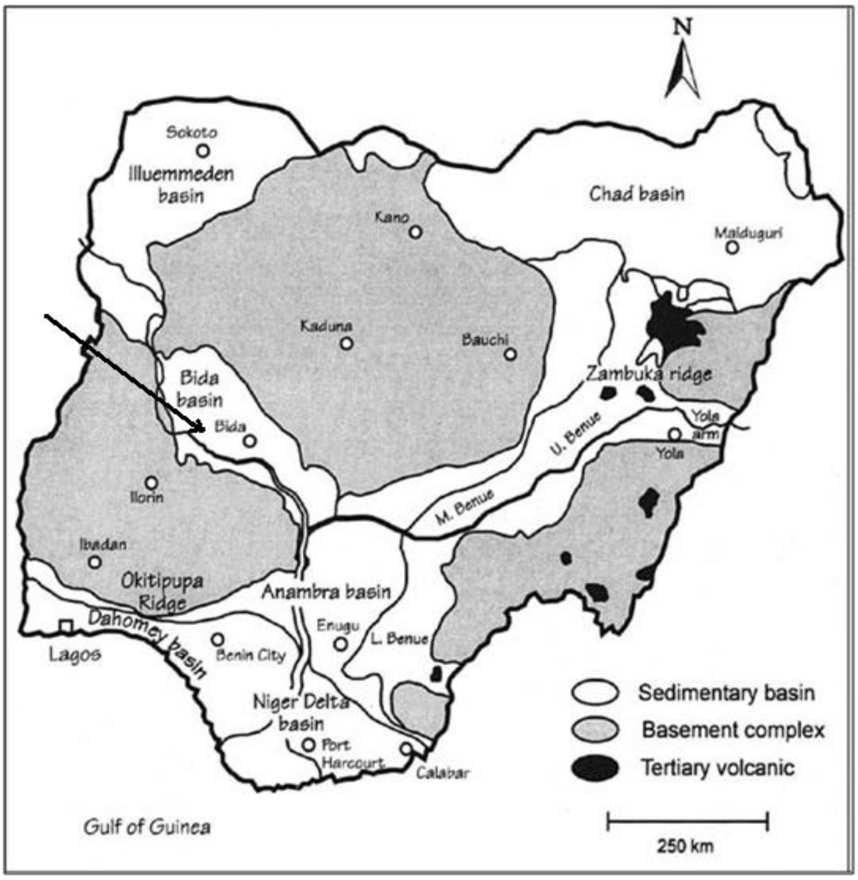


Figure 1: Map of Nigeria showing Bida basin (Obaje et al. 2011)

The stratigraphy and sedimentation of Upper Cretaceous succession of the Bida Basin have been documented by [17] in the central parts of the basin around Bida. Four mappable stratigraphic unites are recognized in this area, namely, the Bida Sandstone (divided into the Doko Member and the Jika Member), the Sakpe Ironstone, the Enagi Siltstone, and the Batati Formation. The collapse of the Mid-Niger and Anambra platforms led to the sedimentation of the Upper Cretaceous depositional cycle commencing with the fully marine shales of the Campanian Nkporo and Enugu Formations which may have some lateral equivalents in the Lokoja Formation of the Bida Basin. Overlying the Nkporo Formation is the sedimentary units of the Mamu Formation. These consist of shales, siltstones, sandstones and coals of fluvio-deltaic to fluvio-estuarine environments whose lateral equivalents are the conglomerates, cross-bedded and poorly sorted sandstones and claystones of the Lokoja and Bida Formations in the Bida Basin.

The Lower Benue Trough which includes the Anambra Basin is considered as the southern extension of the Bida Basin. Initial gravity studies in the Bida Basin put the maximum thickness of the sedimentary successions at about 3.5 km [18] in the central axis. Although the hydrocarbon potential of the basin has not been fully tested with seismic and the basin remains undrilled, both ground and aeromagnetic studies by several studies have outlined the basin configuration ([19]; [20]). A recent spectral analysis of the residual total magnetic field values over several sections of the basin reveals an average depth to the basement rocks to be 3.4 km with sedimentary thickness of up to 4.7 km in the central and southern parts of the basin [20]. In general, sediment thickness decreases smoothly from the central portion to the flanks of the basin .Previous studies on the geology of the Bida Basin were reported in [16]. [21] interpreted the paleo environments of the sedimentary successions in the Southern Bida Basin as ranging from continental to marginal marine and marsh environments for the Cretaceous lithofacies

II. DATA AND METHODOLOGY

The aeromagnetic data which is high resolution data was acquired in digital format from the Nigerian Geology Survey Agency. Fugro Airborne survey completed the nationwide aeromagnetic survey for the Nigerian Geology Survey Agency in 2009, this aeromagnetic survey was flown along a series of NW-SE flight lines (perpendicular to dominant regional geologic strike) spaced at 500m with 2000m tie line spacing in the NE - SW direction. Data were recorded at very small intervals of 0.ls each with 80m normal flight height (see figs. 2 and 3). Spectral analysis of the aeromagnetic data was done using Programme that runs on MATLAB 7, developed by Odegaard and Berg. For the spectral determination of depths to layers of magnetization, the study area was divided into four by four (4x4) blocks containing 16 data points. Geosoft Oasis-Montaj and Surfer 12 software were used for data processing and generation of 2D and 3D plots respectively.

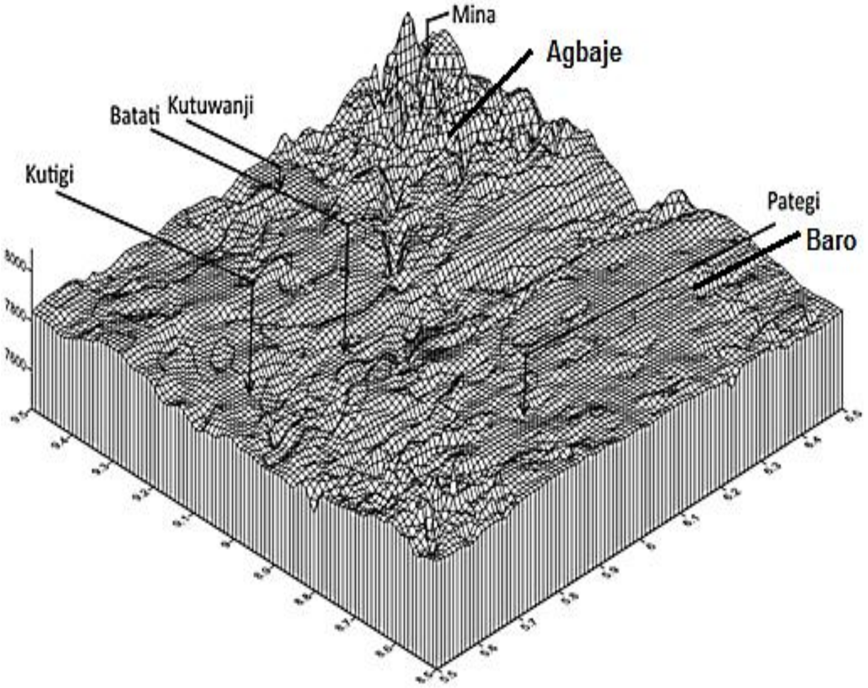


Figure 2: 3D Aeromagnetic Wireframe Map of study Area

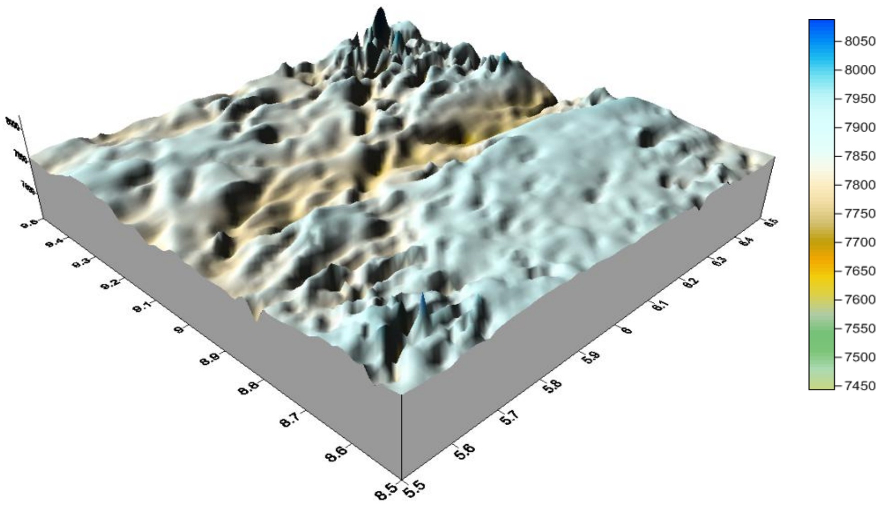


Figure 3: 3D map of the Total Magnetic field Intensity(TMI)

The aeromagnetic data used were subjected to several filtering operations (see fig. 4 for instance). The nature of filtering applied to the aeromagnetic data in this study was chosen to eliminate certain wavelengths and to pass certain wavelengths. Polynomial fitting was applied to the data for regional-to-residual separation, to expose the residual features as random errors and reduction-to-pole was applied to minimize polarity effects on the data (fig.5).

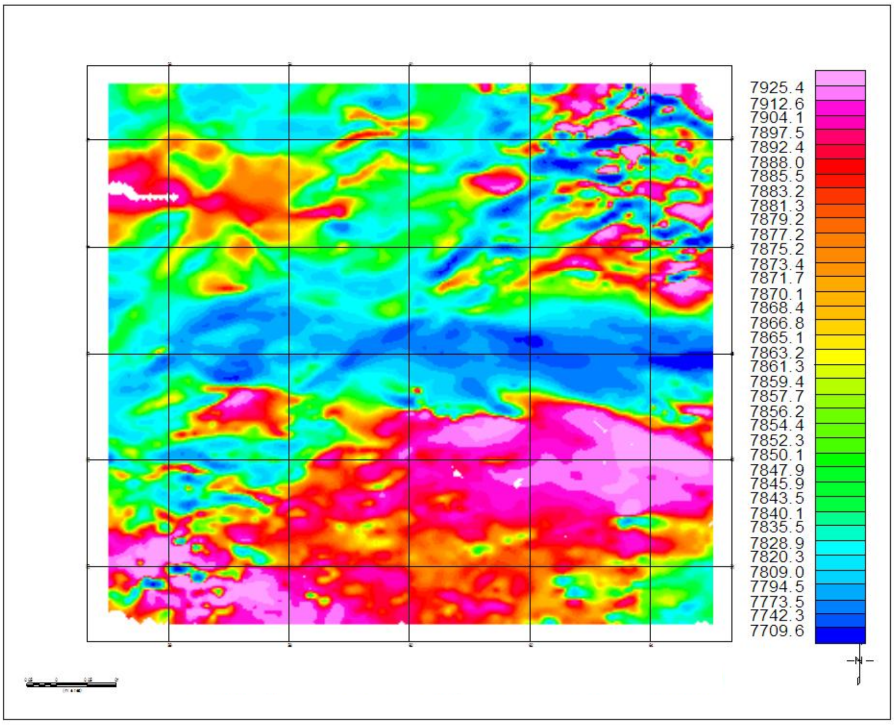


Figure 4: Band-pass Filter Map of study Area

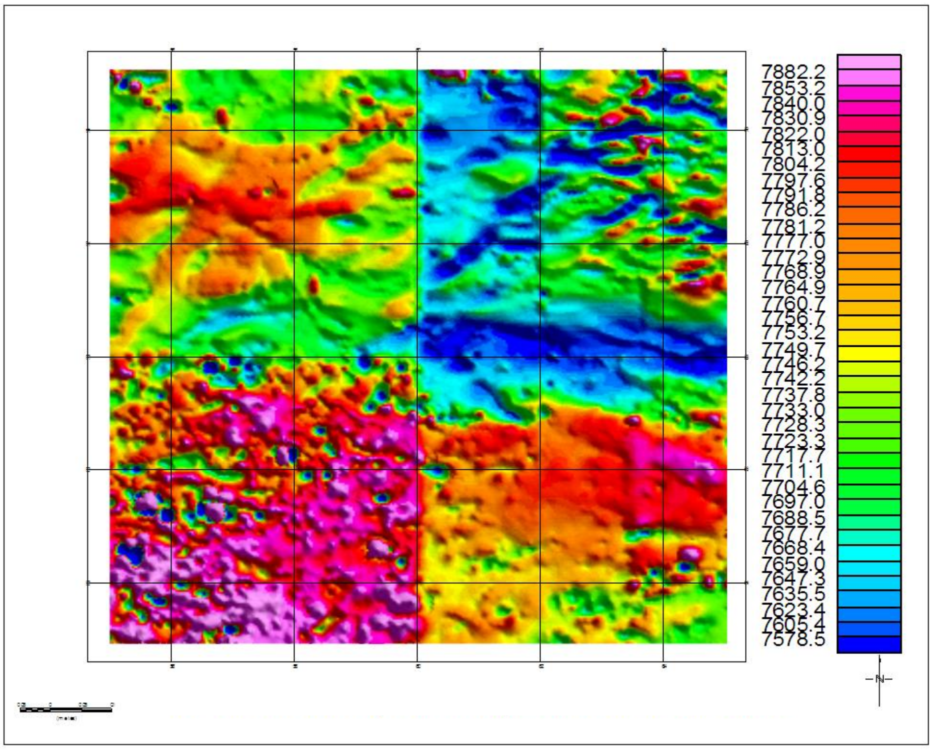


Figure 5: Reduction to pole Map of study Area

A Fourier transformation of the digitized aeromagnetic data was carried out to compute the energy/power spectrum of the data which was then plotted against frequency on a logarithm scale. Depth estimates in the study area were obtained from slopes of the power plots while standard Euler Maps (from index 0-3) were used for structural interpretations.

The spectral depth method is based on the principle that a magnetic field measured at the surface can therefore be considered the integral of magnetic signatures from all depths. The second degree Residual map is shown in figure 6.

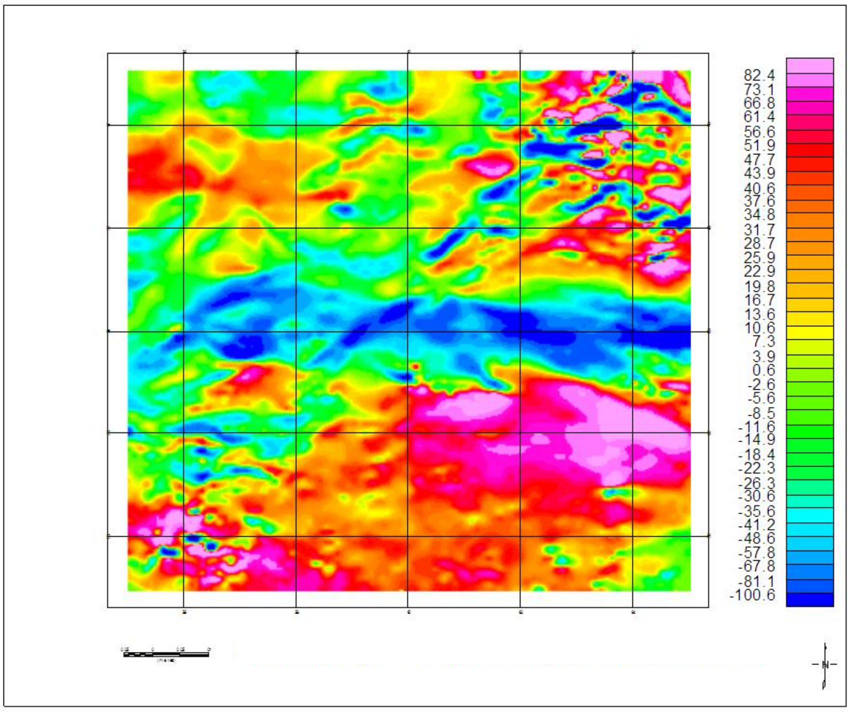


Figure 6: Second degree Residual Map of study Area

The power spectrum of the surface field can be used to identify average depths of source ensembles [8]. This same technique can be used to attempt identification of the characteristic depth of the magnetic basement, on a moving data window basis, merely by selecting the steepest and therefore deepest straight-line segment of the power spectrum, assuming that this part of the spectrum is sourced consistently by basement surface magnetic contrasts. A depth solution is calculated for the power spectrum derived from each grid sub-set and is located at the centre of the window. Overlapping the windows creates a regular, comprehensive set of depth estimates. This approach can be automated with the limitation. However, that the least squares best-fit straight line segment is always calculated over the same points of the power spectrum, which if performed manually would not necessarily be the case.

Considering potential field data, Euler's equation can be written as:

$$(x-x_o)\frac{\partial T}{\partial x} + (y-y_o)\frac{\partial T}{\partial y} + (z-z_o)\frac{\partial T}{\partial z} = N(B-T) \qquad (1)$$

With B the regional value of the total magnetic field and (Xo: Yo: Zo) the position of the magnetic source which produces the total field T measured at (x: y: z). [11] showed that simple magnetic and gravimetric models are consistent with Euler's homogeneity equation. Thus Euler Deconvolution provides an excellent tool for providing good depth estimations and locations of various sources in a given area, assuming that appropriate parameter selections are made.

Though it is a general advantage of the Euler Deconvolution method that it is applicable to all geological models and it is insensitive to the remaining magnetic and geomagnetic inclination and declination, an initial assumption of the source type has to be made. Dependent upon the potential source type, a structural index is chosen. This structural index is also a measure of the distinctive fall-off rate of the geologic feature. For example, the best results for a contact are obtained by structural indices of 0, while for thin two- dimensional dyke structures a structural index of 1 yield the best estimates, as explained in table 1. The number of infinite dimensions describes the extension of the geologic models in space.

Table 1: Structural Indices for Simple Models used for Depth Estimations in 3D Euler Deconvolution

Geologic Model	Number of Infinite Dimensions	Magnetic Structural Index
Sphere	0	3
Pipe	1 (z)	2
Horizontal cylinder	1 (x-y)	2
Dyke	2 (z and x-y)	1
Sill	2 (x and y)	1
Contact	3 (x ,y, z)	0

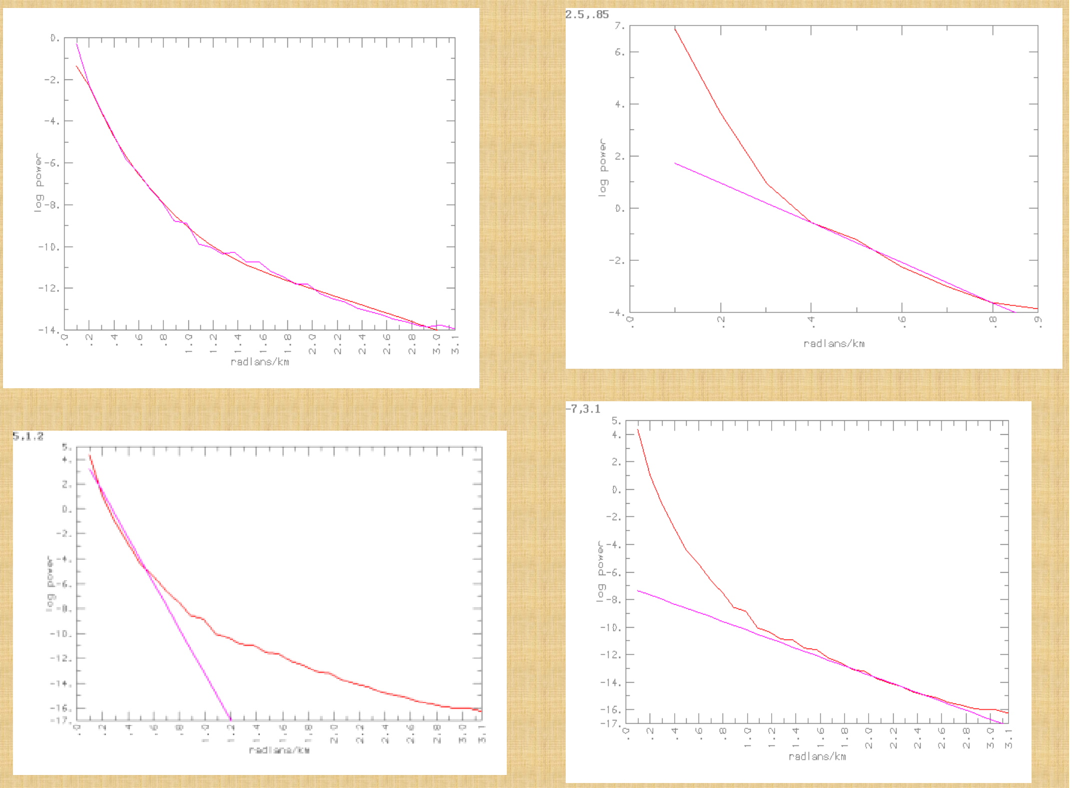
III. RESULTS AND DISCUSSION

Two methods for depth estimation were adopted for this study. They are Spectral Analysis and 3D Euler Deconvolution methods. To estimate basement depth by the first method, the processed aeromagnetic data was transformed to frequency domain using the Fast Fourier Transform (FFT) function to compute the energy (or amplitude) spectrum. This was then plotted on a logarithmic scale against frequency. It is the slopes of the segments so obtained that yield estimates of average depths to magnetic sources of anomalies (see fig. 7 a-d). The FORTRAN program used here is called SPECTRDEP, to determine the depths of the anomalies to their magnetic sources. The study area was divided into 16 overlapping sections. A two layer (D_1 and D_2) depth method was adopted. The results are shown in table 2 - where D_1 represents the depths of the shallower sources and D_2 of the deeper sources.

The first layer depth (D_1) varies from 0.138km - 0.935km with an average depth of 0.622km. The second layer (D_2) varies from 0.742km – 3.974km with an average depth of 3.173km. D_1 values so obtained are the depth values to shallower sources of anomalies in the study area while D_2 values so obtained are the depth values to the basement Complex and therefore depict the sedimentary thickness in the blocks considered (as shown in table 2). The 3D map of the depths to shallower sources of anomalies (D_1) is shown in figure 8 while the 2D and 3D maps of D_2 are shown in figures 9 and 10 respectively.

Table 2: Summary of Spectral depths of study area

LOCATION	SPECTRAL BLOCKS	LONGITUDE		LATITUDE		DEPTH (KM)	
		X_1	X_2	Y_1	Y_2	D_1	D_2
Pategi	A	5.50	5.75	8.5	8.75	0.332	0.742
	B	5.75	6.00	8.5	8.75	0.724	2.764
	C	5.75	6.00	8.75	9.00	0.235	3.375
	D	5.50	5.75	8.75	9.00	0.584	3.974
Baro	E	6.0	6.25	8.5	8.75	0.575	3.234
	F	6.25	6.50	8.5	8.75	0.564	2.282
	G	6.25	6.50	8.75	9.00	0.893	3.864
	H	6.0	6.25	8.75	9.00	0.697	3.985
Bida	I	5.50	5.75	9.00	9.25	0.138	3.157
	J	5.75	6.00	9.00	9.25	0.454	3.256
	K	5.75	6.00	9.25	9.50	0.873	2.865
	L	5.50	5.75	9.25	9.50	0.935	2.687
Agbaje	M	6.0	6.25	9.00	9.25	0.673	3.254
	N	6.25	6.50	9.00	9.25	0.762	3.693
	O	6.25	6.50	9.25	9.50	0.524	2.064
	P	6.0	6.25	9.25	9.50	0.368	2.403



Fig, 7a Power spectrum plots of aeromagnetic data of blocks A- D(Pategi)

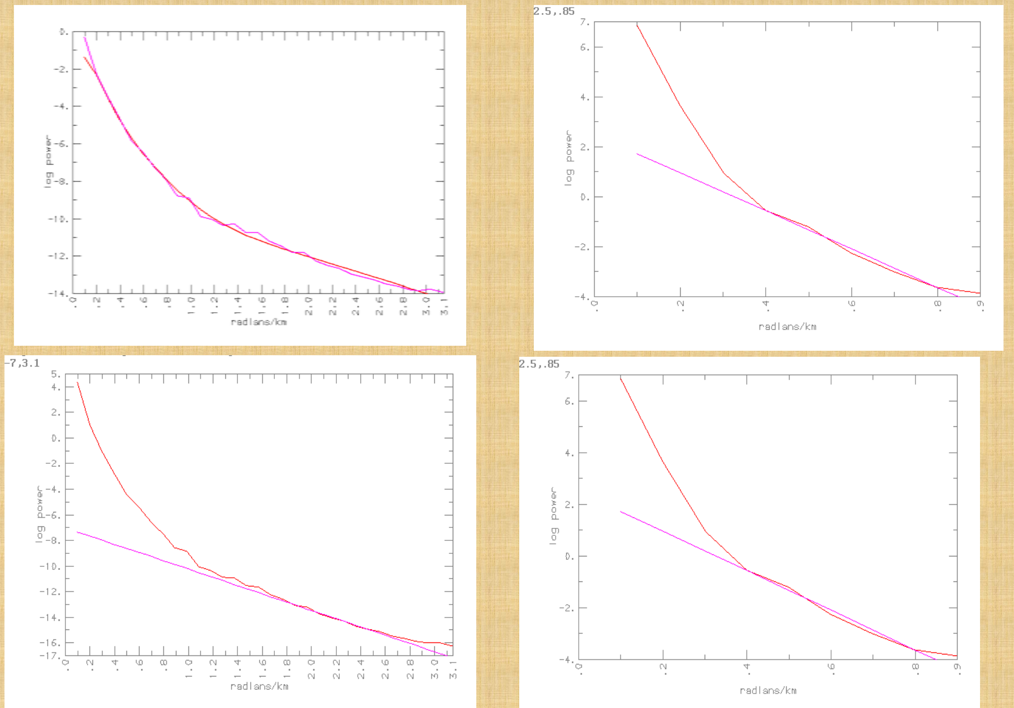


Fig. 7b: Power spectrum plots of aeromagnetic data of blocks E- H(Baro)

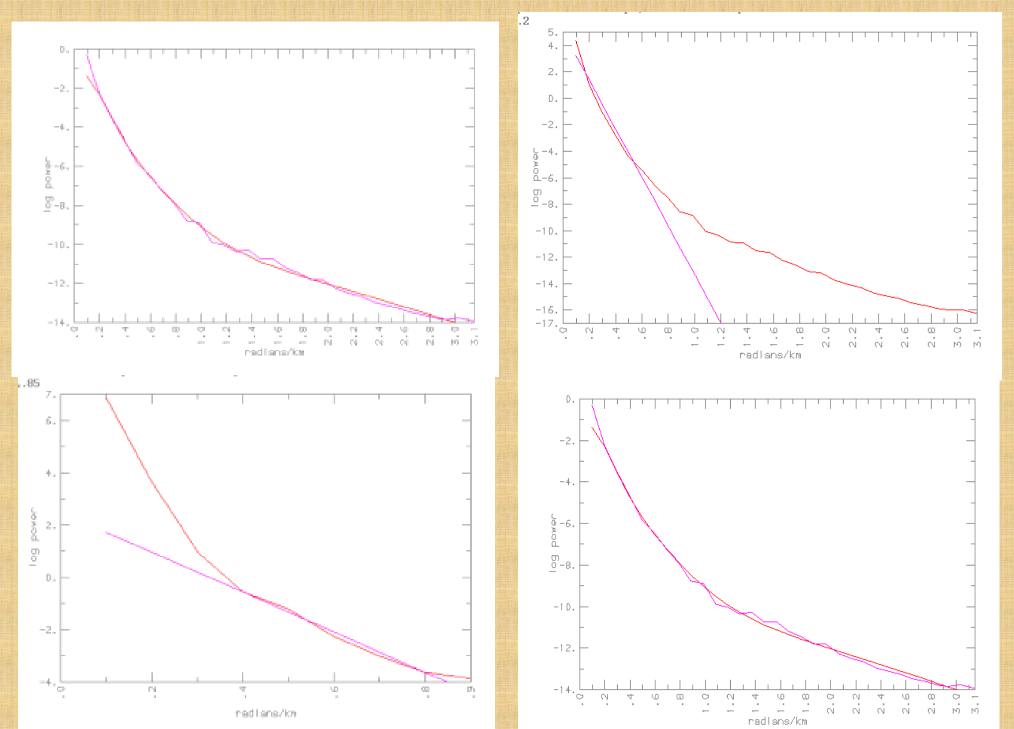


Fig.7c: Power spectrum plots of aeromagnetic data of blocks I- L(Bida)

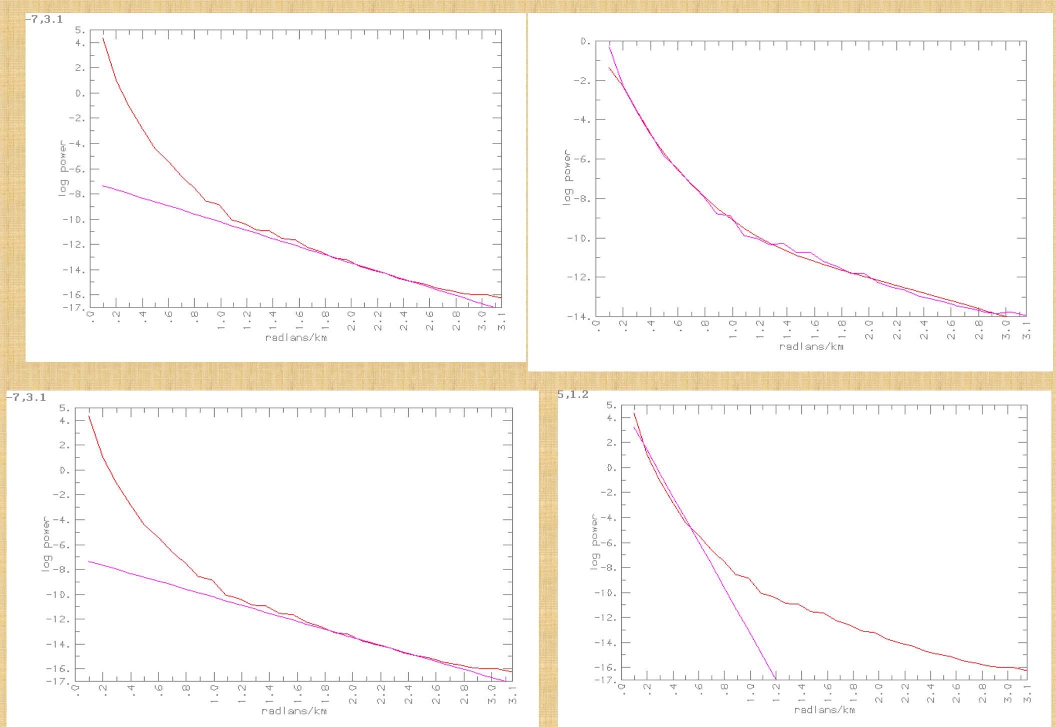


Fig.7d: Power spectrum plots of aeromagnetic data of blocks M- P(Agbaje)

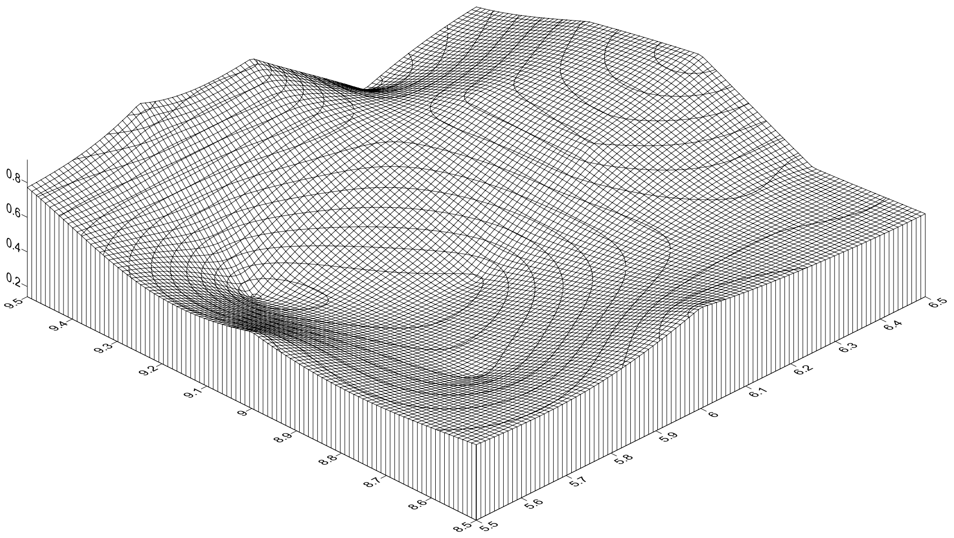


Fig 8: Spectral depth to the shallow magnetic sources(D1) presented as a 3D map

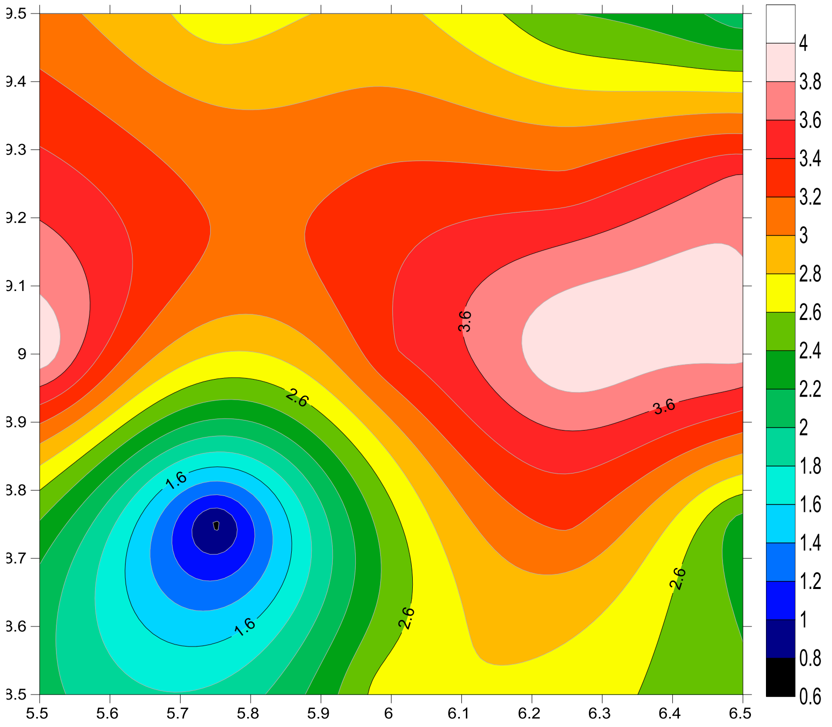


Fig. 9: Spectral depth to the deeper magnetic sources(Basement depth)(D2) presented as image map

Colour application on the contour map of figure 9 improved the delineation of high and low basement depths while Basin architecture and basement morphology of the study area were clearly depicted through the 3D contour maps of the shallower depth (D_1) and the magnetic basement depth (D_2) as shown in figures 8 and 10 respectively.

Depth estimate for a variety of geologic structures such as faults, magnetic contacts, dykes, sills, etc can be made (for Euler Deconvolution method) through the combination of structural indices and estimated depths. The method locates sources of anomaly by the degree of homogeneity which can be interpreted as a Structural Index by relating the potential field with its gradient components. In order words, initial assumption of the source type has to be made (structural index).

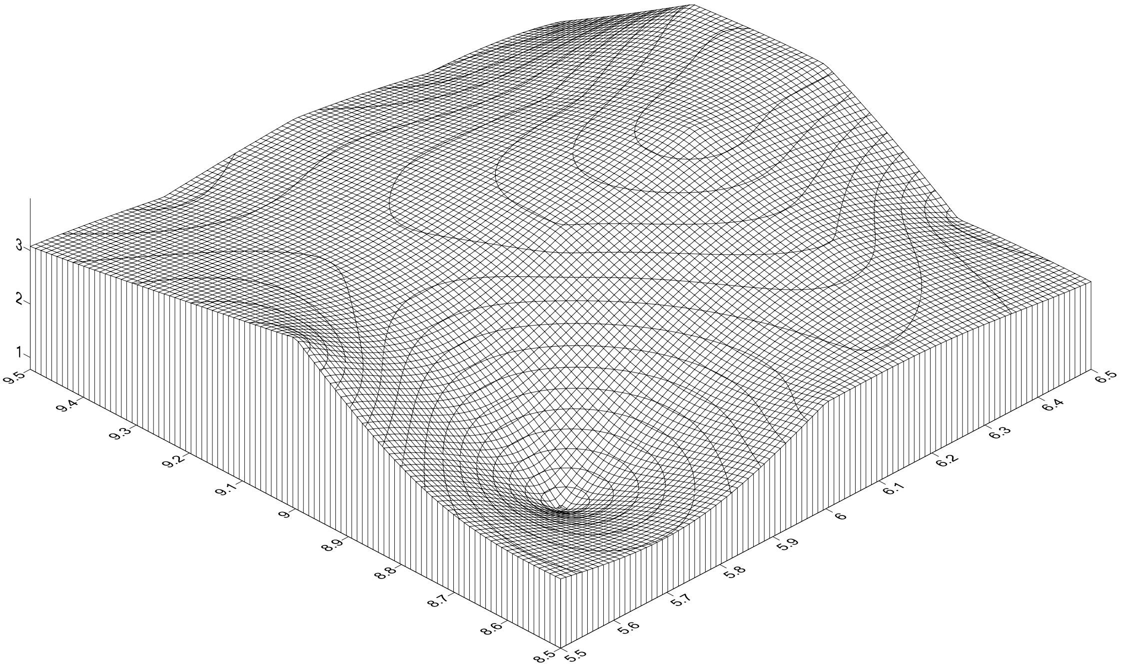


Fig. 10: Spectral depth to the deeper magnetic sources (Basement depth)(D2) presented as 3D map

In this study, structural indices of 0-3 were used, while solutions were gotten for the standard Euler deconvolution using the different structural indices. Thus the Euler deconvolution suggests a depth to the source horizon of 0m to above 3000m. The highest occurrence of structures in form of Pipes and Horizontal Cylinders occur at depth ranges of 1km to 2km in the SW and NE portions of the study area and also at the NW and SE portions of the study area but at depths of 2.5km to 3km (fig. 11c). Another occurrence of structures is Sill and Dyke at depth range between 2500m – 3000m towards the Eastern part of the study area (fig. 11b). Results of depth estimates as obtained by modeling at structure indices of 3 and 0 are highlighted in figures 11d and 11a respectively.

IV. CONCLUSION

The processed aeromagnetic data of the study area can be said to be tectonically active. The analysis of the Regional and residual anomalies suggests intrusive active regions. The total field of the aeromagnetic data presented as a 3D surface map showed a highly intruded basement surface. These intrusions took a preferentially weak path that can be termed as fault and the cooling of the associated magma led to magmatic segregation within the study area. The Results of the spectral analysis of the aeromagnetic data over the study area suggest the existence of two main source depths. The depth to basement or deeper source D_2 varies between 0.742km and 3.985km; these deeper sources reflect the Precambrian basement. The topographic relief of the basement composition is due to the structural and topographic relief of the basement surface, lateral variations in basement susceptibilities and intra-basement features like faults and fractures. The depth obtained from this study seems reasonable and agree with those from previous workers. These depths/ thicknesses estimated would not encourage petroleum maturation and accumulation owing to their not being thick enough. This is with exception of the far eastern region (Minna and Pategi areas) where appreciable thicknesses were estimated. Other regions are qualified for solid mineral exploration due to great tectonic/ structural features revealed.

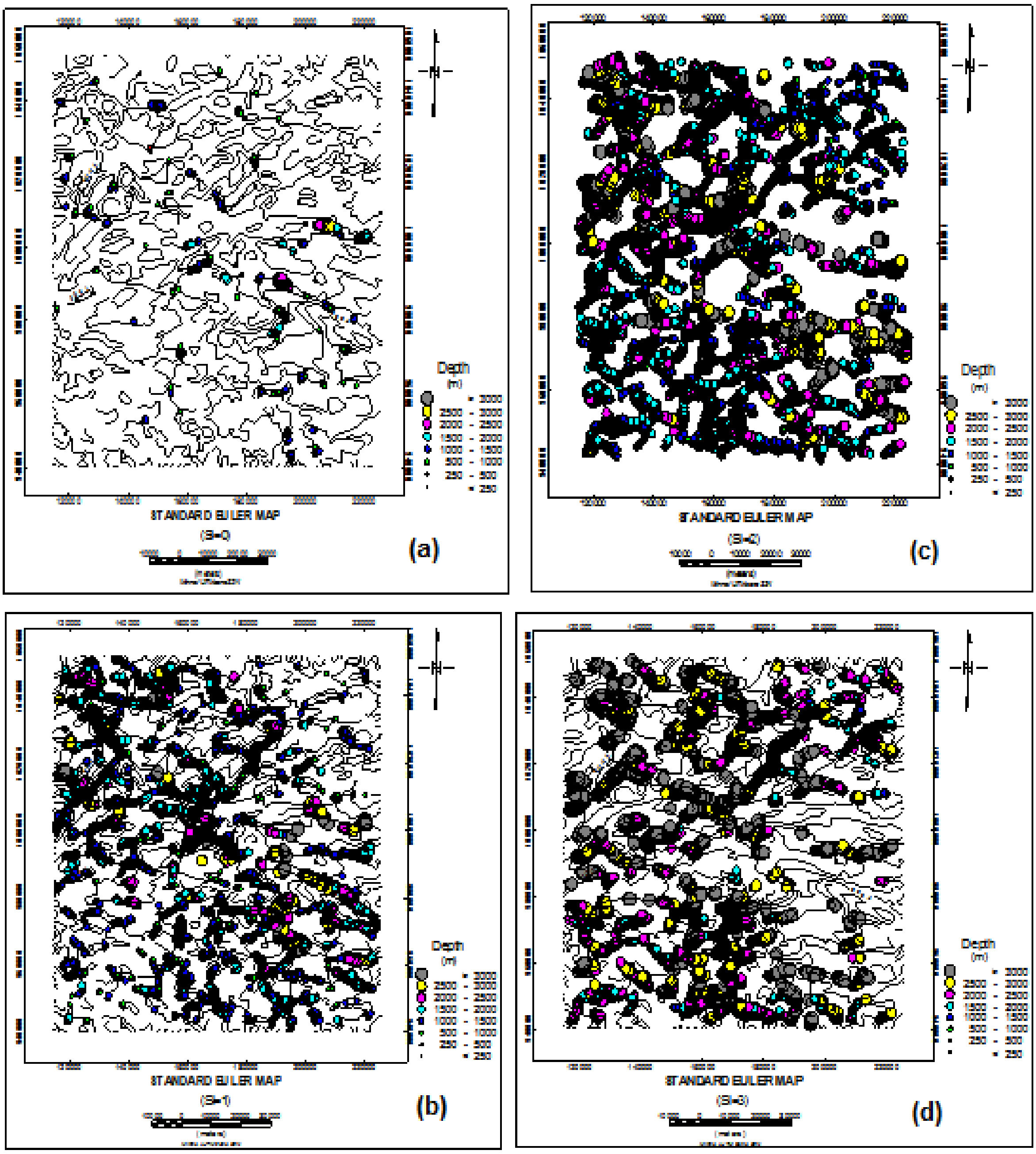


Fig. 11(a-d): **Standard Euler Maps of the study area for Structural Indices 0(a), 1(b), 2(c), and 3(d).**

The structural elements observed in the study area as modeled from Euler deconvolution are predominantly located in the Eastern and North-Eastern regions at depths of 2.5km to 3km for Eastern zone (contact) and 1km to 2km for North-Eastern zone (horizontal cylinder/pipe). NW and SE regions also show deeply rooted horizontal/pipe solutions at depths of 2.5km to above 3km. We insinuate therefore that the Eastern and Northeastern region could be explored for hydrocarbon while the South Western region (around Pateji) can be explored for mineral resources.

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