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Interpretation of Amplitude Response to Shallow and Deep-Seated Anomalies of Bamenda Massif (Sheets: 303, 304 and 305), Southeastern Nigeria

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Abstract:

The study on interpretation of amplitude response to shallow and deep-seated anomalies of Bamenda Massif (sheets: 303, 304, and 305) Southeastern Nigeria has been evaluated. The data sets used are digitized maps of Aeromagnetic data. The study area was characterized into four distinct zones such as A, B, C and D. Zone A occur in the Northern portion and it is characterized by linear anomaly of amplitude 66.2 - 98.5nT. Zone B and C primarily share the same structural grain connecting the southwest and southern portions of the study area where they are characterised with large "bull eye" and narrow shaped anomalies. Zone D occupies the western and central portions of the study area showing features of magnetic highs and lows due to sporadic intrusions. The analysis review lineament structures aligned in a NE-SW and NW-SE trends which is in similar pattern to the initial rifting of the southern Nigerian margin system. Zone A, B and C are bound by intrusives of igneous origin. However, the interconnectivity of the structural lineaments makes them stand out as pathways for mineralization. Thus, most of the lineaments are believed to be located at a depth range of <246.5m to 258.2m, 258.2m to 437m, 212.9m to >626.1m and 769.2m to 1039.7m within the subsurface rocks.

Key words - **Aeromagnetics, Bamenda Massif, Structural features, Magnetic Anomalies.**

I. INTRODUCTION

Apparently, geophysical concepts deal with the use of basic principles and laws of physics in solving geological problems such as detection of zones of mineralization, understand structural features on basement and overly sedimentary rocks in a given geological setting. The aim is to demonstrate the value of interpreting geophysical data and in context of existing geological principles. It is shown that such an interpretation is a strong and sound method of geological mapping of the surface and subsurface, more particularly of mineral exploration.

However, it is essential to do a profound structural geologic history or a reconstruction of the structural events that could aid quantitative and qualitative interpretation of the regional geology and tectonic processes that have structured the existing rock setting in a given area. All of these can be analysed by carrying out a geophysical survey (i.e., land or airborne survey) to detect both surface and subsurface rock changes using some geophysical tool (magnetometer).

[1] worked on geological interpretation of the high resolution Aeromagnetic data over Okigwe-Udi Area, Anambra Basin, Nigeria. In this report, 3-D Euler Deconvolution and 2-D Spectral Inversion Methods were used to show a two-layered depth model of shallower and deep magnetic sources as well as linear features.

[2] worked on Petrologic and structural characteristics of the basement units of Bansara area, Southeastern Nigeria. The analysis reveals that; deformation, metamorphism and intrusions are the dominant geodynamic features in the area which has led to the structural changes in the rocks.

Perhaps, Aeromagnetic geophysical method plays a distinguished role when compared with other geophysical methods in its rapid rate of coverage and low cost per unit area explored. In many sedimentary basins, magnetic anomalies arise from secondary mineralization along fracture planes or fault zones, tectonic contact, etc., which are often revealed on Aeromagnetic maps as linear features [3; 4; 5]. Hence, the study uses Aeromagnetic and geological data to provide new interpretations (map and section-view) of crustal architecture in parts of Bamenda Massif, South-eastern Nigeria.

II. GEOLOGIC SETTING OF THE STUDY AREA

The study area is located within latitudes $05^{0}30'00''$N to $06^{0}03'00''$N and longitudes $07^{0}0'0''$E to $09^{0}30'00''$E (Fig.1). The map shows areas of mapped rock exposures, where structural features were observed, and measurements of strike and dip were done. The study area cuts across three distinct sheets (303, 304 and 305) of Bamenda Massif, South-eastern Nigeria. (Fig. 1 and 2).

It is believed that the study area, Bamenda Massif belongs to the Precambrian Basement Complex of Nigeria in Age [6]. The oldest rock in the South-eastern area is the banded gneisses and the youngest is dolerite which is part of the igneous intrusives in the area. These rock units are overlain by Cretaceous - Tertiary sediments of the Calabar Flank [3].

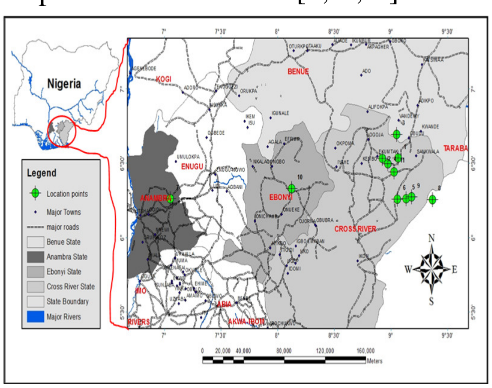


Fig. 1 Location map of the study area (Source: GIS software, 2017).

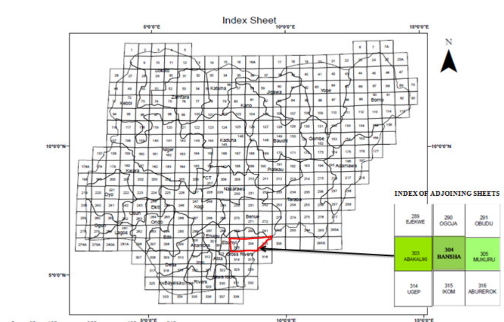


Fig. 2: Index map showing the position of sheet 303, 304 and 305 of the study area [7].

Perhaps, most of the mappable rock units in the area are of metamorphic origin, although, intruded by igneous rocks such as pegmatite, granodiorite, diorite, dolerite, etc., [8]. The rocks are bounded to the West by Cretaceous and younger sediments of Benue Trough, to the East of the prominent Cameroon Volcanic Line, and to the North of the Ogoja Province and the famous Obudu Plateau.

The study area represents a tectonic wedge of the terminal portion of the Western Bamenda Massif of Cameroon into Eastern Nigeria [9; 10; 11; 12; 13; 14; 15; 16]. However, the study area is divided into three distinct sheets (i.e., 303, 304 and 305) and were later merged together as a single unit during the software interpretation.

Consequently, sheet 303 consist mainly of sedimentary rocks that are cretaceous in Age and sheet 304 consist of Migmatite-Gneiss Complex that are overlained by sedimentary rocks. While sheet 305 consist mainly of the Pan African Older Granite.

III. AEROMAGNETIC DATA AND ANALYSIS

A. *Data Set and Source*

The data set used in this research work includes Aeromagnetic data (of sheet 303, 304 and 305) and was obtained from the Nigerian Geological Survey Agency (NGSA), Abuja, Nigeria. However, a digitized geological map was obtained as part of the data from the Nigerian Geologic Survey Agency (NGSA), Abuja, Nigeria.

The survey activities were carried out in Nigeria between the year: 2003 and 2009. And the survey was conducted by Patterson Grant and West (PGW) Consultants of Canada. Perhaps, the objective of the survey is to put in place efficient, effective and transparent tools for easy access by investors, of airborne

geophysical survey data of Nigeria. It is therefore, the intention to accelerate mining sector investment because of wide dissemination of airborne data.

B. Technical Details of the Airborne Geophysical Survey of Nigeria

The survey covers 128,180-line kilometers and has the following flight parameters:

- Total Lines in km: 1,104,174km
- Flight Line Spacing: 500 meters
- Terrain Clearance: 80 meters
- Flight Line Direction: NW-SE
- Tie Line Spacing: 2km
- Tie Line Direction: NE-SW

The survey includes the following geophysical methods:

- Magnetic total field
- Gamma ray spectrometry
- Horizontal magnetic gradient enhancement.

However, the data processing was done by Patterson Grant and West (PGW) of Canada and the maps were in the scale of 1: 100,000.

C. *Data Format*

Grid data are analysed using Oasis Montaj Geosoft in a grid file format. Line data are delivered in Oasis Montaj Geosoft format and ASCII file format and a format description file accompanies each data file.

IV. METHODOLOGY

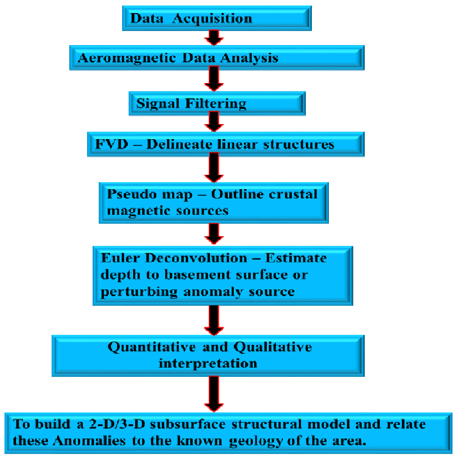


Fig. 3: A technical work flow of the steps taken in this research (Where FVD is first vertical derivative).

V. AEROMAGNETIC DATA ANALYSIS

A. Total Magnetic Intensity Anomaly Map

The Aeromagnetic intensity maps describe structural and anomalous changes due to tectonic and deformational processes. Perhaps, the changes in magnetic anomalies in different parts can results to changes in magnetic mineral composition, remanent magnetization and structural trends within the rocks. Thus, the magnetic contour lines portray variations in magnetic intensity with some parts in the range of -8.8nT to 29.3nT, 30.8nT-50.3nT, 61.5nT-82.9nT and 78.8nT-95.5nT respectively (Fig. 4).

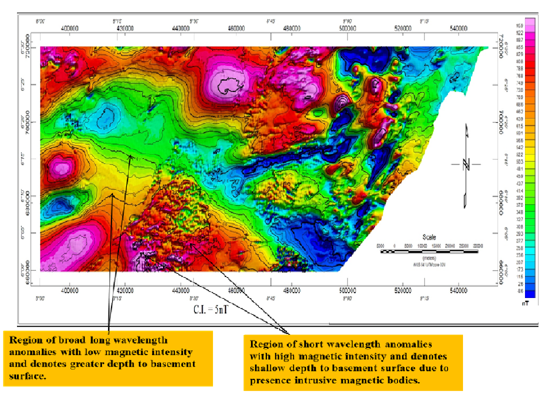


Fig. 4: Total magnetic intensity contour map and wavelength anomaly trends of the different zones.

B. Reduction-to-Pole

It is pertinent to do a phase shift operation which is referred to as the reduction-to-pole approach on the observed magnetic field. The operation affects the phase and amplitude of the magnetic anomalies. However, the reduction to pole (RTP) operation transforms the observed magnetic anomalous changes into the anomaly effects that would have been measured if the magnetization and ambient field were both vertical. This in effect, puts the limits of the magnetic anomalies directly over their sources to distinguish changes in depth to basement surface, hence, making magnetic interpretation easier and more reliable for computing magnetic parameters for subsurface evaluation [17; 18], Fig. 5.

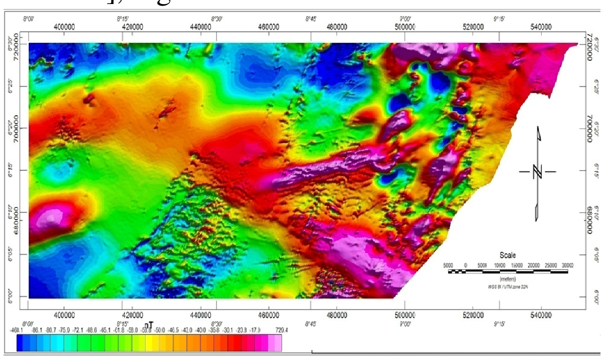


Fig. 5: Reduced-to-pole map.

C. *Reduction-to-Equator*

To improve the resolution quality and better define the nature and source of the anomalies at low latitudes, there is the need for transforming the analytic maps in the space domain to Fourier domain, thus, this is the case of the reduction to the equator method. In the space domain, the analytic transformation corresponds to convolution of the initial signal with a specific operator. Although, computations are done in the Fourier domain where the convolution is replaced by the simple multiplication (Fig. 6).

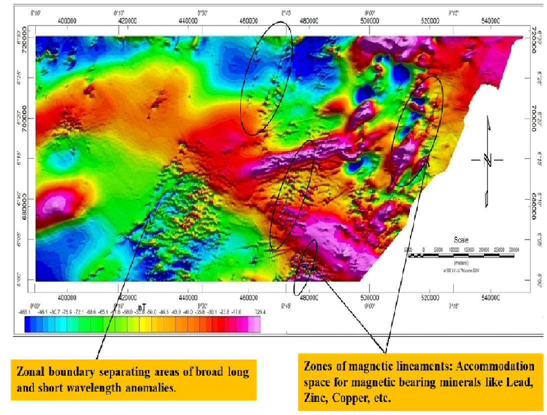


Fig. 6: Magnetic intensity map showing subsurface reflections of magnetic anomalies with response to their wavelength and amplitude characteristics.

D. *First Vertical Derivative*

Determination of the magnitude of improved resolution quality of the first vertical derivative (FVD) of the residual field, consequently, the reduce-to-equator allows a map to be produced showing various Aeromagnetic lineaments features which can be interpreted as faults and the displacement of the blocks that create ample space for mineral accumulation. Particularly, considering the Northern, Southern and Eastern parts of the structural maps (Fig. 7)

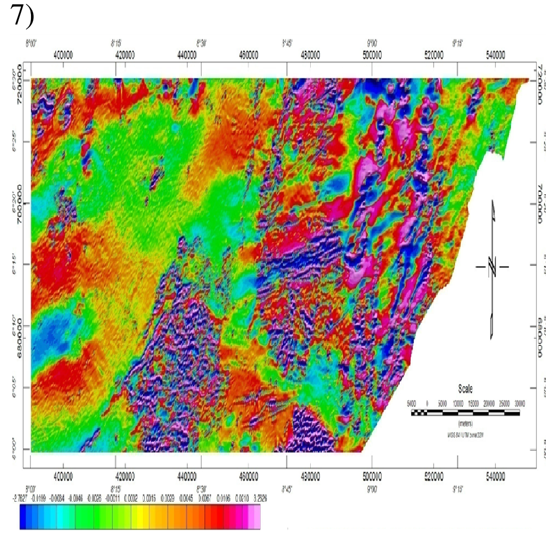


Fig. 7: First Vertical Derivative Map.

E. *Euler Deconvolution*

The objective of the Euler deconvolution process is to determine the shape and corresponding depth estimations of geologic sources of magnetic and anomalies along profiles. Euler deconvolution is based on solving Euler's homogeneity equation (1) [17; 18]:

$$(x-x_0)\frac{\partial \mathrm{M}}{\partial x}+(y-y_0)\frac{\partial \mathrm{M}}{\partial y}+z_0\frac{\partial \mathrm{M}}{\partial z}=N(\mathrm{B}-\mathrm{M}) \quad \text{.... (1)}$$

where B is the regional value of the total magnetic field and (x_0, y_0, z_0) is the position of the magnetic source, which produces the total magnetic field M measured at (x, y, z). N is so called structural index for each position of the moving window; an over-estimated system of linear equations is solved for the position and depth of the magnetic sources [17; 18].

Thus, Euler deconvolution can be applied to profiles and therefore, assumes that the field is symmetrically transverse to the profiles, so ∂M / ∂y = 0. However, the total field can be the sum of a regional field and the anomaly due to the point source, then:

$$(x-x_0)\frac{\partial \mathrm{M}}{\partial x}+z_0\frac{\partial \mathrm{M}}{\partial z}=N(\mathrm{B}-\mathrm{M}) \quad \text{....... (2)}$$

By moving the operated window from one location to the next over the anomaly, multiple solutions for the same source are obtained.

The Euler method [17; 18] has been applied to a profile selected on the TMI map after subtracting the regional trend. The focus of the Euler analysis is on the constraining of the depth of perturbing body responsible for the regional anomalies (Fig. 8).

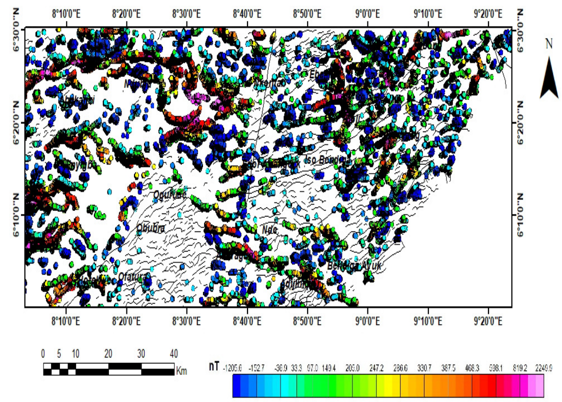


Fig. 8: Superimposed lineament trends on Euler Deconvolution map.

VI. RESULTS AND DISCUSSION

A. Interpretation of Aeromagnetic data

This study demonstrates the use of digitized Aeromagnetic maps (Fig. 4) for mapping and analysing lineaments in the Basement Complex region (Bamenda Massif) of South-eastern Nigeria. Several methods were adopted in the determination of depth to basement surface in this study, as well as, draw and interpret profile lines from magnetic maps (Fig. 11).

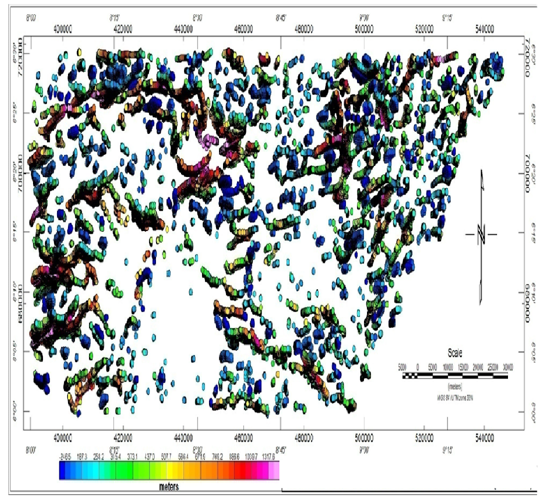
In this way, the depth estimation approach was used to determine magnetic parameters such as amplitude, width of the body, depth to basement surface and anomaly source, dip, magnetic susceptibility, percentage magnetite and to know the possible rock type existing in the four different zones (A, B, C and D) across the study area (Fig. 9, 10 and 11). Hence, these magnetic parameters are needed for the characterization of the magnetic anomalies across the zones in relation to the already existing geology at the subsurface area.

Indeed, there are intrusive bodies of circular, elliptical, narrow shape and sporadic dikes all over the area due to subsurface movement of basement rocks that is triggered by tectonic and deformational processes which may have caused the North-eastern part to move upthrown relative to the South-western part which moved down thrown (Fig. 12). This in effect, shows several depths to basement surface in the different zones of the study area.

However, Zone A has depth estimates in the range of <246.5m - 258.2m in areas like Nkonfab and Ebem, probably, due to uplift of subsurface materials. Other area like Abakaliki and Ndubia show greater depth to basement surface of 717.1m - 1241.2m.

Zone B has depth estimates of 769.2m - 1039.7m and 1039.7m - > 1317.6m in areas like Hotekwe and Enyigba, indicating the down thrown part of the study area. The depth to basement surface and source producing the magnetic anomalous intrusives in this zone is deep seated. Consequently, zone C shows similar upward movement of basement materials as a reflection of sporadic and narrow dike intrusions, therefore, has depth estimate of 152.3m - 274.5m in areas like Ofatura and 437m - 769.2m in Abaragba area.

While zone D has deep source to basement surface in areas like Kanyang, Boje and Ubong having depth values of 769.2m - 1039.7m and 1039.7m - > 1317.6m respectively (Fig. 8, 9 and 10). Some mineral deposits like Lead, Zinc, copper, Tin, Platinum, etc, were observed across shear zones and tectonic contacts in the area; Iron ore deposits were observed in Kanyan (around Mbe Mountain); Fool's Gold, Chalcopyrite and Lead deposits were observed in Abakaliki area; Manganese in Buanchor area and Barite in Irruan (around Afi Mountain) of the study area.



Blue= < 246.5-258.2m; Yellow= 437.0-769.2 Pink= 1039.7- > 1317.6m
Green= 258.2-437.0m; Red= 769.2-1039.7m Black= < 0

Fig. 9: Euler Deconvolution Map and depth estimate to basement undulating surface.

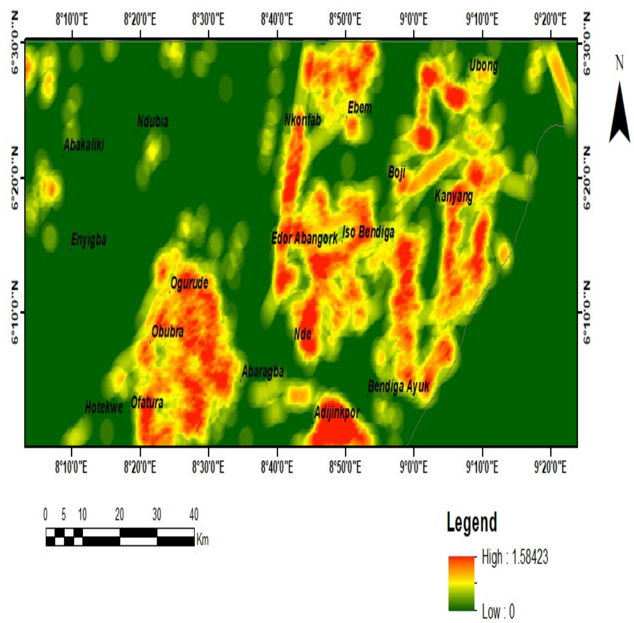


Fig. 10: High resolution aeromagnetic map showing regions of high magnetic intensities of subsurface intrusives and area of occurrence.

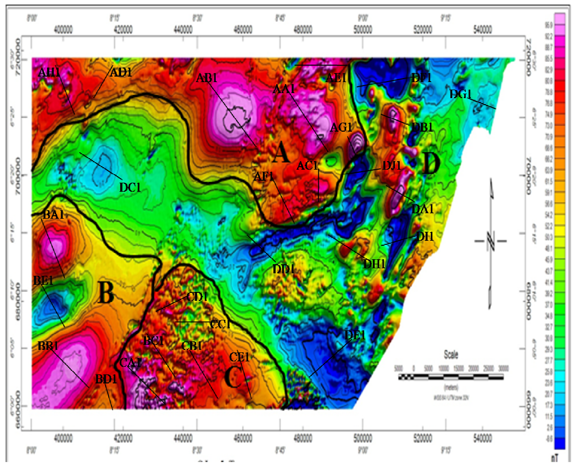


Fig. 11: Total magnetic contour map showing areas of profile lines for graphical magnetic interpretation with respect to different zones of magnetic anomalies.

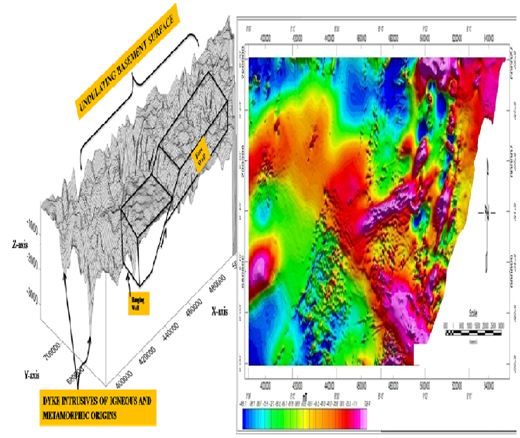


Fig. 12: A juxtaposed section of 3-D model of subsurface basement topography and reduce to pole aeromagnetic map.

B. *Structural Modelling*

The 3-D model of Fig. 13 shows a superimposed fault model which demonstrate the displacement of the blocks (i.e., hanging and foot wall) on both sides of the fault plain. In this way, the displacement can be observed in a juxtaposed fashion of the reduce to pole Aeromagnetic map which shows regions of high and low amplitude of magnetic intensities on different parts of the map (Fig. 13). To the right of the reduce to pole Aeromagnetic map, there is high magnetic intensity which is because of the intrusive magnetic dykes at the North-eastern part of the 3-D model (Fig. 12 and 13). However, this illustrates the up thrown movement of the foot wall and the down thrown movement of the hanging wall (resulting to a normal fault) in the 3-D model.

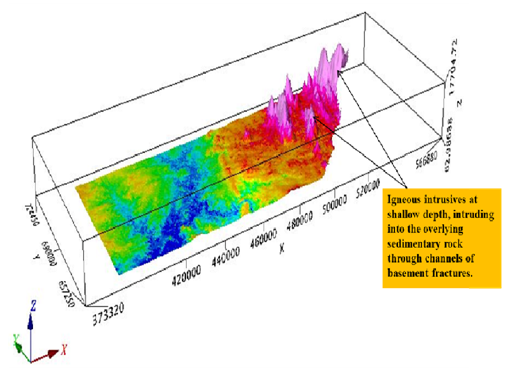


Fig. 13: 3-D model of igneous intrusives at shallow depth.

VII. CONCLUSION

Several zones across the study area were analysed to understand subsurface events that may be responsible for the changes in structural and magnetic anomalies. In this case, zone A is characterized around the Northern part of the study area where the magnetic intensity contour lines range from 73-96.9nT with high amplitude anomalies. Zone B covers the South-western part of the study area that is characterised with broad and long wavelength anomalies which typifies that, a deep seated causative body could be responsible for the anomalous changes at depth.

Thus, zone C displays numerous narrow shaped anomalies in the form of (volcanic pipes) and they are of high amplitude ranging from 50.2-61.9nT. The magnetic intensity contour lines range from 73.0nT - 88.7nT due to sporadic dikes of basic and ultrabasic origin and seems to cluster together. Furthermore, the North-eastern part of zone D shows the presence of granitic rocks that are Pan-African in Age. This is believed to be formed from volcanic igneous intrusives from basement rocks that are near surface.

The intrusives have an average dip of 54.2^0 with depth to basement surface ranging from 0.102km - 0.549km. The towns associated in this zone are Boji which is few kilometers West of Kanyang and some kilometers South of Ubong in the Northeastern part of the area. The rock types formed by basic intrusives are diorite, biotite granite and dolerite.

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