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INTERPRETATION OF ANOMALY PATHWAYS FOR MINERALIZATION IN PARTS OF BAMENDA MASSIF, SOUTHEASTERN NIGERIA

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ABSTRACT - The geophysical perception of integrating Aeromagnetic and Landsat data for interpreting anomaly pathways vis-à-vis mineralization in parts of Bamenda Massif, Southeastern Nigeria, is an elegant way of understanding the tectonic frame work through structural geologic models of the subsurface rocks in the area. The data sets were analysed and interpreted models were produced using softwares such as Oasis Montaj, ArcGIS, Envy and Erdas respectively. The aim is to delineate linear geologic structures such as faults, contacts, joints and fractures (lineament analysis) within the study area in a bid to unravelling the structural patterns (trends), and the gross subsurface geology of the area which would in no doubt help in a better understanding and characterization of mineral zones in the area. The area shows zones of sporadic and narrow shaped intrusives that are clustered from the broad-long wavelength and large ''bull eye'' shaped anomalies that are equispaced. Clearly, these structural features indicate different tectonic stresses resulting to large scale structural deformation. Thus, this makes them complex and some of these structures are evident in the Eastern part of the map where they trend in the NE-SW strike direction as possible zones for mineral exploration. Therefore, most of the fracture zones 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. The interconnectivity of the fracture zones makes them stand out as pathways for mineralization.

Key words – **Aeromagnetics, Landsat, Bamenda Massif, Structural features, Mineralization, Magnetic Anomalies.**

I. INTRODUCTION

Geophysics is an applied science that uses basic laws and principles of physics in solving geological problems. It is a long-established science that has contributed greatly to the understanding of geological phenomena. It concerns the determination of subsurface properties and structure of the rocks within the earth by quantitative measurement of physical fields at the surface. Several alternative forms of the geophysical methods may be used for extraction of geological properties from subsurface rocks, depending on the conditions and manner of surveying: airborne, ground, borehole, etc. Each of these alternatives has its instrumental, methodical and interpretational peculiarities (Ukaigwe, 2000).

In this case, Geophysical data are but one set of parameters that add to the description of rocks and their structural relationships. By assessing such parameters in relation to other known data both geologists and geophysicists gain fresh insights into the exploration problems to be solved. This coordinated approach may seem obvious, but in practice is rarely applied (Ukaigwe, 1997).

The study on ‘’Interpretation of anomaly pathways for mineralization in parts of Bamenda Massif, Southeastern Nigeria can be viewed from Aeromagnetic and Landsat imageries. These imageries fall within sheets 303, 304 and 305 of the study area. Perhaps, this study is significant in geology and geophysics, as it would try to interpret structural elements for mineralization or mineral resources in the area. Thereby, considering specify areas of anomalous intrusive bodies found in these areas as well as relate these attributes to the existence of geothermal and geotectonic regime in the area. The aim is to delineate linear geologic structures such as faults, contacts, joints and fractures (lineament analysis) within the study area in a bid to unravelling the structural patterns (trends), and the gross subsurface geology of the area which would in no doubt help in a better understanding and characterization of mineral zones in the area.

However, several scholars have worked recently on the interpretation of subsurface anomalies and structural features that serve as pathways for mineralization and other related geologic attributes in the Southeastern region of Nigeria. Such work includes those of (Ugwu & Nwosu, 2009; Selemo & Akaolisa, 2010; Chikwendu & Diugo, 2011; Oden, et al., 2012; Amah, et al., 2012; Alain, et al., 2012; Adetona & Abu, 2013; George, et al., 2013; David & Marius, 2013; Obi, et al., 2013; Goodhope & Luke, 2013; Onuba, et al., 2013; Opara, et al., 2014; Ezema, et al., 2014). Their works are related to the resolution of magnetic lineaments, analyse its relationship to the tectonic fabric and to estimate the depth of perturbing bodies.

II. GENERAL GEOLOGY OF THE REGION

The study area is part of the Bamenda highlands of Cameroon into Southeastern Nigeria and it lies within latitudes 06^{0}0'00"N to 07^{0}0'00"N and longitudes 08^{0}0'00"E to 09^{0}30'00"E with the famous Obudu Plateau in the North-eastern part located North of Ikom in Cross River State. It is believed that the study area, Bamenda Massif belong to the Precambrian Basement Complex of Nigeria in age (Ekwueme, et al., 1995).

The oldest rock in the Southeastern 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 (Ekwueme, 2003). 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., (Rahaman, et al., 1981).

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 as shown in **Fig. 1**. The study area is located within latitudes 06^{0}0'00"N to 07^{0}0'00"N and longitudes 08^{0}0'00"E to 09^{0}30'00"E as shown in **Fig.**

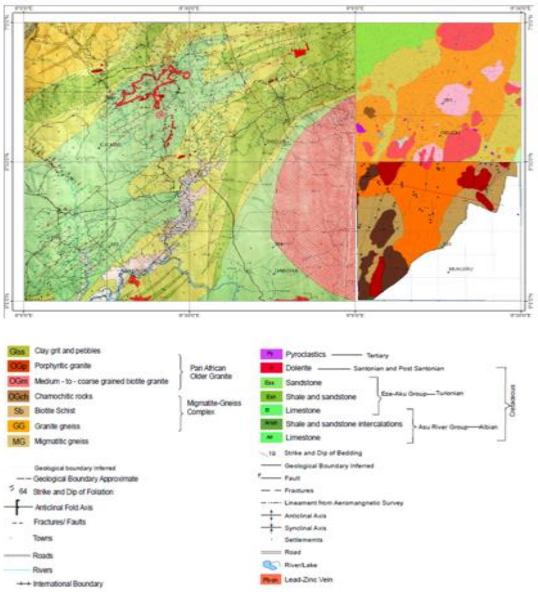

Fig. 1. Geologic map of the study area (Nigerian Geological Survey Agency, 2006).

III. MATERIALS AND METHODS

A. Data Sets and Source

The data sets used in this research work include Aeromagnetic, Landsat data (sheets: 303, 304 and 305) and Geologic map (scale of 1: 100,000) of the study area which were obtained from the Nigerian Geological Survey Agency (NGSA), Abuja Federal Capital Territory, Nigeria.

B. Aeromagnetic Data Analysis

The concept of Aeromagnetic data processing involves accurate enhancement of the short-wavelength and linear features. In that regard, the Aeromagnetic data was first re-gridded with a grid-cell spacing of 252m and was subjected to regional/residual separation to isolate short-wavelength signals which are more suitable for high-resolution mapping of shallow magnetic boundaries from long-broad wavelength signals. The regional/residual separation was made by upward continuation of the total magnetic intensity aeromagnetic grid. In this way, the upward continuation transformation attenuates the high-frequency signal components and therefore, tends to emphasize deep, regional-scale magnetic anomalies. Subtraction of the low-frequency upward-continued data from the original grid produces a residual map that is enhanced in the short-wavelength signal. The enhancement of magnetic anomalies that are associated with faults and other structural discontinuities were achieved by the application of Vertical Derivative to the residual map in **Fig. 5**. The reprocessed Aeromagnetic data set is significantly enhanced in high frequencies and is much better suited to detailed regional shallow mapping and analysis of basement magnetic boundaries.

C. Landsat Data Analysis

Satellite imagery provides digital image of the earth at specific wavelength within the electromagnetic spectrum. Various features on the earth either natural or man-made give distinguishable signature of the electromagnetic radiation. This signature helps categorize the data into different features for various geographic applications such as land cover, vegetation types, terrain conditions, built-up areas etc. It appears to be a solution to providing data owing to its synoptic capability, spectral, spatial and temporal resolution. In addition to that, the technique acquires spatially continuous data unlike field sensors (airborne and space borne) applied in hydrological studies.

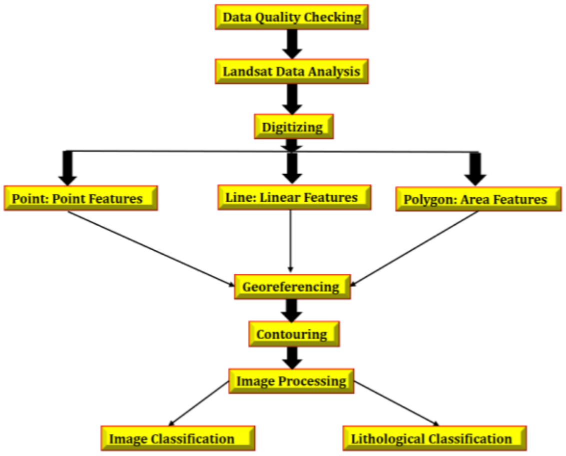

Fig. 2. A technical work flow of the Landsat data analysis.

IV. RESULTS AND DISCUSSION

A. Results of Aeromagnetic Data

Indeed, geophysical data are embodiment of subsurface changes in relation to the various geological processes such as deformation, displacement, tensional and compressional stresses that can result to structural features emanating from subsurface to near surface Earth. However, these sorts of geophysical data can be acquired by land or airborne surveys. Consequently, the data are processed and interpreted to understand the structural elements at the subsurface rocks from which possible mineralizations can be explored and exploited in **Fig. 3, 4 and 5**.

Basically, the regional anomaly is caused by deep seated effects like volcanism, tectonism and intrusion at depth in **Fig. 4, 6 and 7**. However, this can be interpreted during processing of the Aeromagnetic data which is done using sophisticated softwares (such as Oasis Montaj) to remove the regional effect to obtain the residual anomaly in **Fig. 4 and 5**.

The vertical derivative map and other improved resolution maps that are associated with it, demonstrate a vivid picture of the subsurface pervasive structures. However, these structures can be seen in the Northern part of the map that shows a major fault line which runs down to the Southern part and another in the South-western part of the map. The configuration of positive anomalies in the Northern and Southern parts of the area may be attributed to deep-seated basement structures and this in effect, suggests that the total magnetic intensity of the anomalies is strongly influenced by the regional tectonics existing at the subsurface basement rocks in **Fig. 5, 6 and 7**. However, the Aeromagnetic maps which illustrate the presence of fracture zones in different parts of the area, show that these zones are prominently oriented in the NE-SW and NW-SE directions in **Fig. 5**.

This separates zones of sporadic and narrow shaped dike intrusions that are clustered together from the broad-long wavelength and large "bull eye" shaped dike intrusions that are equispaced. Clearly, these structural features are associated to long and short wavelength anomalies, indicating that they are connected to different tectonic stresses resulting to large scale structural deformation. Thus, this makes them complex and some of these structures are evident in the Eastern part of the map where they trend in the NE-SW strike direction as possible zones for mineral exploration in **Fig. 5**.

Therefore, most of the fracture zones 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 in **Fig. 8**. The interconnectivity of the fracture zones makes them stand out as pathways for mineralization.

In addition, the Aeromagnetic map in **Fig. 3** was further interpreted quantitatively for computing and magnetic parameters that would aid the understanding of subsurface activities that gave rise to the changes in magnetic anomalies, the possible source of the anomalous zones, the geometry of the anomalies, depth to basement surface, width of the causative body, amplitude and wavelength of the anomaly structures in **Table- 1**.

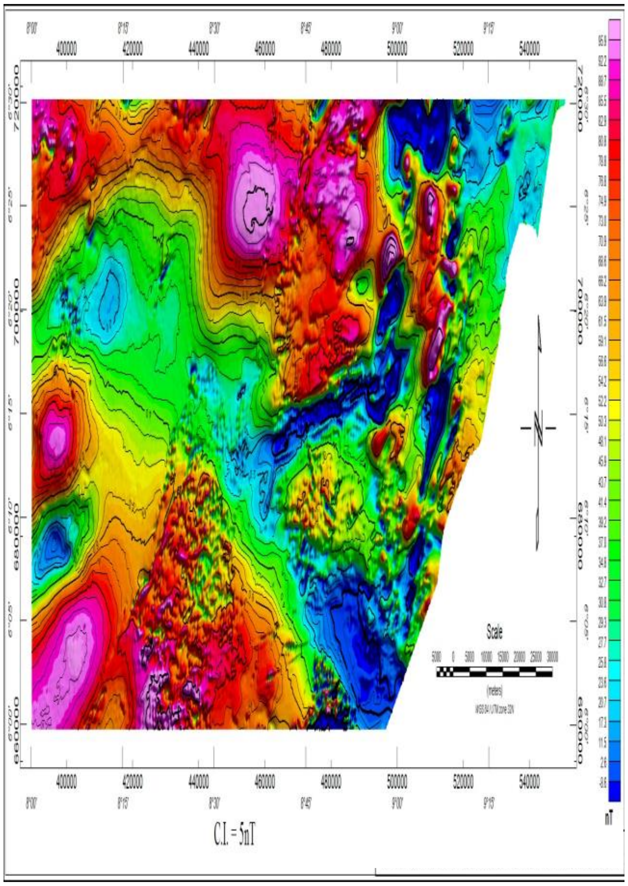

Fig. 3. Total magnetic intensity contour map of Bamenda Massif.

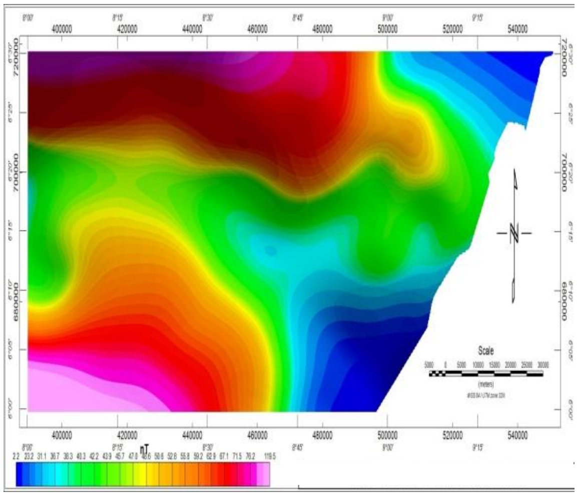

Fig. 4. Regional map of Bamenda Massif

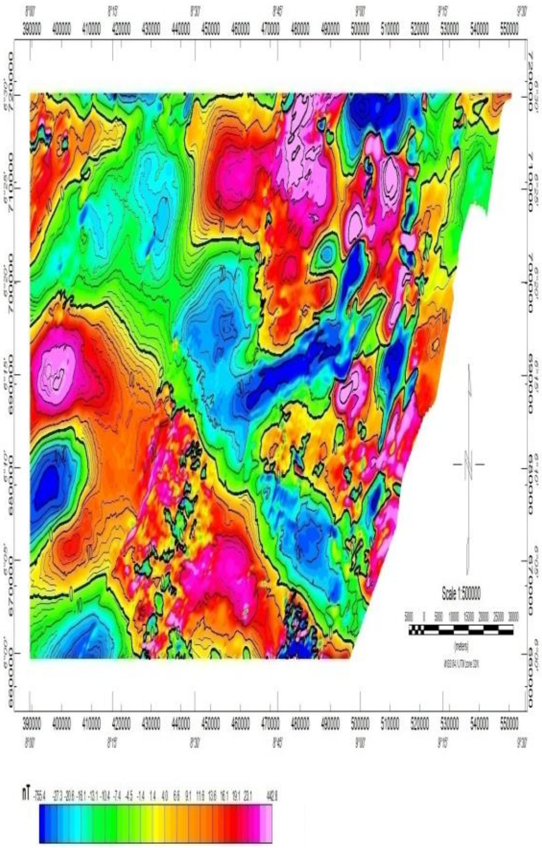

Fig. 5. Residual map of Bamenda Massif.

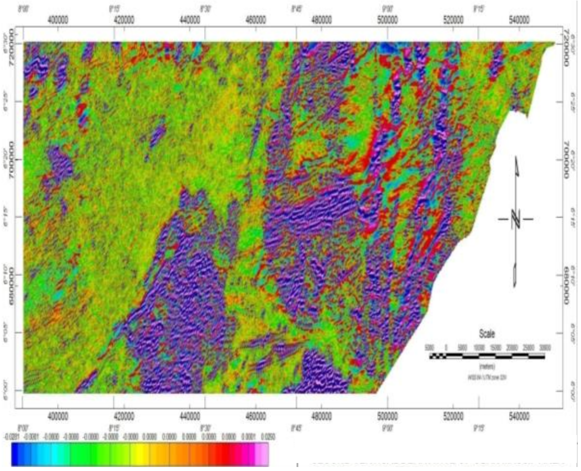

Fig. 6. Vertical Derivative Map of Bamenda Massif.

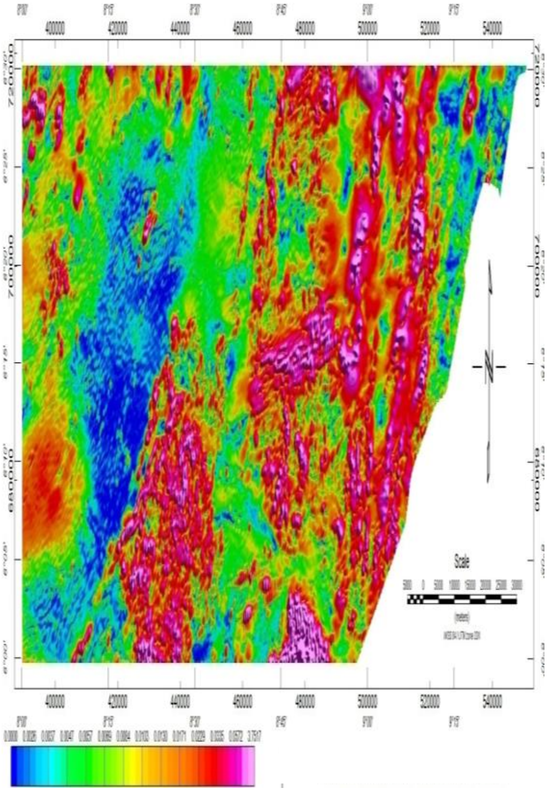

Fig. 7. Analytical Signal Map of Bamenda Massif.

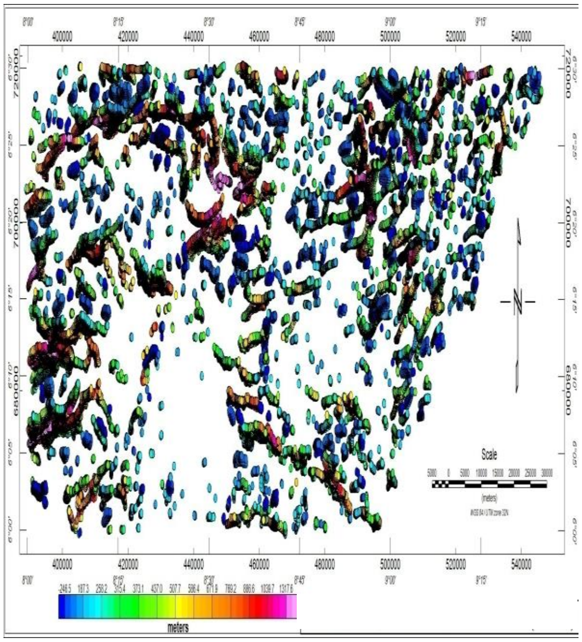

Figure 8. Euler Deconvolution Map and depth estimate to basement undulating surface (Note: The following coloured spots have depth estimates of: blue = <246.5 – 258.2m; yellow = 437.0 – 769.2m; = 1039.7 - >1317.6m; green = 258.2 – 437.0m; red = 769.2 – 1039.7m and black = <0).

B. Results of Landsat Data

The regional geologic structures in parts of Southeastern Nigeria have a complex geology, however, the use of integrated approach of Aeromagnetic and Landsat data can vividly delineate the subsurface structural attributes for possible mineralization of magnetic minerals in veins and fissures.

The models in Fig. 9 and 10 confirm the morphological difference and the tectonical subdivision into tentative sequence of events corresponding to the central part of the Landsat data and to identify the tectonic boundaries separating them at depth.

Apparently, the Landsat data shows a clear view of the shear zone in **Fig. 11**). Typically, this zone illustrates subsurface structural deformation activities that is related to the rifting of the Southern Nigeria margin system. However, a reconstruction of the structural events on the Landsat map that is on top of the 3D model in **Fig. 11** shows that a large scale structural deformation could be responsible for the rifting and then, drifting of the two adjacent blocks in the form of a shearing motion which resulted to faulting and uplift of the adjacent blocks in **Fig. 10 and 11**.

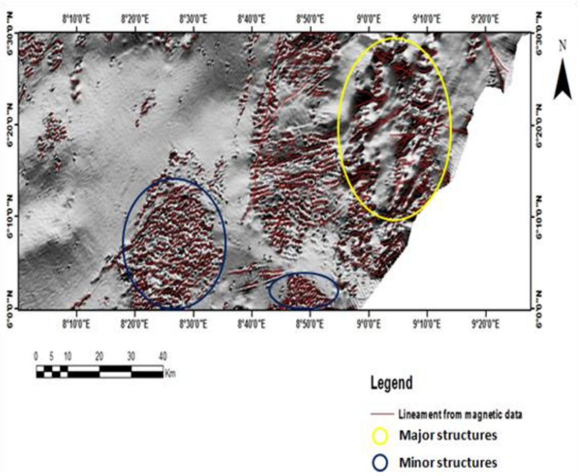

Fig. 9. Lineament map from Landsat data showing areas of major and minor structures within the study area.

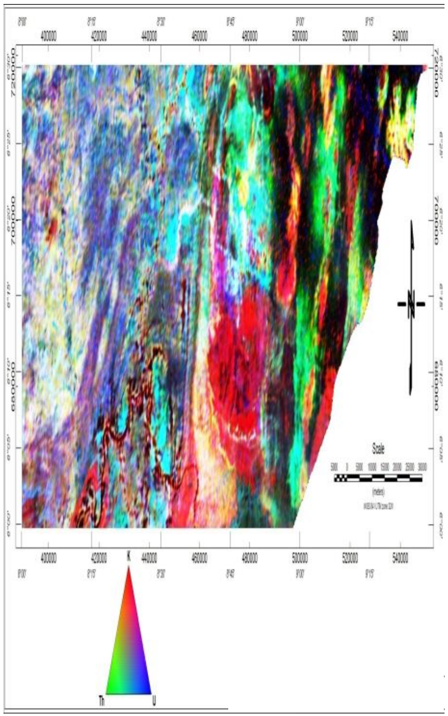

Fig. 10: Ternary image map defining regions of magnetic anomalies with the help of response from radioactive elements beneath the earth.

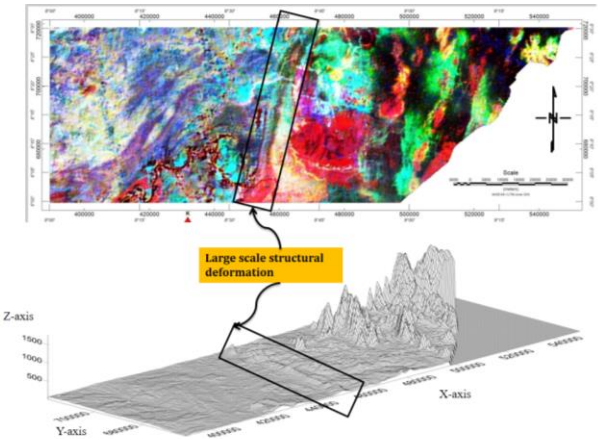

Fig. 11. Large scale structural deformation on both Landsat imagery (at the top) and 3-D structural model (at the bottom).

Table-1 Quantitative parameters computed from Aeromagnetic map.

S/N	PROFILE ID	Depth, Z (m)			ΔT (nT)	Dip (degree)	K (c.g.s.)	W (m)	% Magnetite	Possible rock type
		H.S.D	S	P						
1	AA_1	1123.2	537.6	979.2	98.5	10	0.0045	326.4	1.4	Dolerite
2	AB_1	936	892.8	964.8	89	39	0.00403	312	1.2	Granite gneiss
3	AC_1	270.4	268.8	374.4	78.5	46	0.00356	90	1.1	Porphyritic Granite
4	AD_1	206.7	173.4	945.9	70.8	15	0.0032	68.7	0.98	Diorite
5	AE_1	276.9	108.6	261.9	79	28	0.0036	87.3	1.10	Porphyritic Granite
6	AF_1	912.6	198.6	897.3	75	31	0.0034	299.1	1.05	
7	AG_1	219.7	246.6	368.1	66.2	52	0.0029	82.2	0.92	Diorite
8	AH_1	162.5	197.4	395.1	71.2	42	0.0032	65.8	0.98	
9	AI_1	408.2	228	252	69.5	49	0.0031	84	0.95	
10	AJ_1	878.8	370.8	835.2	91.3	13	0.0041	278.4	1.26	Granite gneiss
AVERAGE		539.5	322.26	627.39	142.98	32.5	0.0035	169.39	1.094	

V. DISCUSION

The study area is the Bamenda Massif shown on Aeromagnetic and Landsat maps. This area occupies part of the South-eastern region of Nigeria and extends up to the Cameroon volcanic ridge. The data sets were analysed and interpreted models of Aeromagnetic and Landsat were produced using geophysical softwares such as Oasis Montaj, ArcGIS, Envy and Erdas respectively.

However, this study demonstrates the use of Landsat imagery, digitized Aeromagnetic and geological maps in **Fig. 1, 3 and 9** for mapping and analysing lineaments in the Basement Complex region of South-eastern Nigeria. The extracted lineaments were geophysically analyzed (region-residual separation) to determine their trends and anomalous intensities to generate lineament maps for subsurface evaluation in **Fig. 3, 4, 5, 6, 7, 8 and 9**.

Indeed, the fracture analyses of the lineament characteristics indicate that the area has numerous long and short fractures whose structural trends are striking mainly in the NE-SW and NW-SE directions in **Fig. 5, 6 and 7** and in a similar pattern to the initial rifting of the Southern Nigerian margin system. However, the cross-cutting lineaments are relatively high in areas around the North-eastern, Southern and South-western parts of the study area, and relatively low in the other areas in **Fig. 6 and 7**.

It is worth noting, that as depth increases, signal amplitude in the different parts of the study area contained in the data, decreases or decays in **Fig. 3, 5 and 8**. Therefore, the deeper the anomaly, the lower the anomaly amplitude which has longer (broad) wavelength and poor resolution. While the shallower the anomaly (i.e., those at shallow depth), the higher the anomaly amplitude which produces shorter wavelength and better resolution quality. However, anomalies located at greater depth but are seen to portray lower anomaly amplitude would be processed for improving the resolution quality for a reasonable geological and geophysical interpretation in **Fig. 5**.

Thus, the magnetic parameters computed is interpreted both qualitatively and quantitatively in order to establish a regional tectonic framework by creating a model that would in turn used to make meaningful geologic interpretation about the thickness of the sedimentary cover, a structural modeling, source producing the anomaly, susceptibility of the anomaly, depth to basement and anomalous zones that are associated with mineralization in the area and relate these anomalies to the known geology of the study area in **Tables-1**.

VI. CONCLUSION

The geophysical perception of integrating Aeromagnetic and Landsat data for interpreting anomaly pathways vis-à-vis mineralization in parts of Bamenda Massif, Southeastern Nigeria, is an elegant way of understanding the tectonic frame work through structural geologic models of the subsurface rocks in the area.

However, analysis of the Aeromagnetic data reviewed certain geophysical parameters about the subsurface anomalies formed within the basement and overlying sedimentary rocks. Thus, these parameters which describe the properties of these anomalies within the rocks show an average depth to basement surface of 539.5m; Anomaly amplitude of 142.98nT; Dip of 32.5^0; Magnetic susceptibility of 3.5×10^{-3}c.g.s unit; Width of 169.39m; Percentage magnetite of 1.094 and the possible rock types observed are Dolomite, Granite-gneiss, Porphyritic-granite and Diorite respectively.

Furthermore, analysis of the Landsat data displays some peculiarities in defining the structural trends/pathways for mineralization. In this way, the structures formed within the zones may have been triggered by tectonic stresses within the rocks. And these stress components result in the formation of structural lineaments in the Northeastern, Southern and Southwestern parts of the area.

The sequence of events from the different models reviewed rifting and drifting processes within the rocks, giving rise to large scale structural deformation of these rocks. The deformational process created openings within the rocks in the form of cracks, fissures, veins, crevasses, etc., that could serve as accommodation space for mineralization during magmatic differentiation at depth.

VII. ACKNOLEDGEMENT

This paper is part of Ph. D Thesis that was elaborate at the University of Port Harcourt.

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