THE USE OF ANALYTIC AND FIRST DERIVATIVE TECHNIQUES TO GAIN INSIGHT INTO AEROMAGNETIC ANOMALY PATTERNS IN PART OF IKARA, NIGERIA

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Abstract: In order to understand structurally, the patterns of subsurface geological features of a basement area due to their various rock properties, especially magnetite content, geophysics is always the answer. Such rock types include pegmatite, migmatite, biotite granite, porphyritic granite, biotite hornblende, etc. The first vertical derivative and analytic signal techniques have been applied to the aeromagnetic data of Ikara, to delineate the subsurface structures. The magnitude maxima of the vertical gradient of the residual magnetic intensity and the analytic signal for the contact locations of the lineaments were determined to be -28.7 and 21710.7 nT/m, respectively. These lineaments were found to be trending in the NE-SW and NW-SE directions, leaving a quite space (free of anomalies) in the central part of the study area. These lineaments in the basement could likely be associated to the Pan-African orogeny, since Nigeria as a country known to be lying within the vast pan-Africa ($650 \pm 150 Ma$) mobile belt. The results provide important information on geologic features of the area that has not been documented.

Keywords: Aeromagnetic, analytic signal, derivative, lineament, mineral vein, polynomial

Introduction

A powerful tool for any positive and effective mineral exploration, especially in basement settings, is comprehending the relationships between faults (lineaments) and flow of mineral through conduits. This comprehension can only be developed through mapping fault patterns within the basement setting and establishing their connections at depth. The deformation occurs in brittle ways, where the rocks change shape by fracturing. Joints are the most common fractures (Maltman, 1990). Faults, fractures, joints and other geological structures, are always the products of rock deformations due to forces caused by internal movements within the earth (Maltman, 1990). The existence of faults and other geological structures, makes the migration and trapping of mineralized fluid, possible. The basic works of geologists is the inspection and recognition of lineaments, and rock outcrops (Alkali and Gaiya, 2011). In the case of unexposed lineaments and other geological structures like accurate direction of mineral veins, the geologists are limited. Of course artisanal miners are more limited. However, most faults are difficult to locate and map due to their complex nature, shallowly or deeply buried (Grauch, 2002).

Over the years aeromagnetic applications have been employed in different geological studies and they play important roles in tracing lithological contacts and recognizing geological structures like faults, lineaments, dykes and layered complexes. The regional aeromagnetic study of anomaly map brings out the regional geological patterns and structural features and provides an exceptional background for interpretation for specific purposes. However Aeromagnetic data can be used alongwith conventional geological maps for various earth resource evaluation applications (Reeves, 1990).

Local mining have been the source of employment for some inhabitants in the study area. They always resorted to a trial and error method in tracing particular trend or pattern of a mineral vein or other geological structures of interest. Hence, the need to provide some helpful structural information about trends/directions of mineral veins and other structures in the area.

To delineate the subsurface structures of an area, there are many filtering techniques commonly used in geophysical surveys. In this paper, only first vertical derivative (FVD) method used for delineation of linear structures; analytic signal which can be used for boundary detection and probable structure responsible for contacts, boundaries, etc. have been used, to bring out aeromagnetic anomalies patterns/trends around part of Ikara, north central Nigeria.

Geology of the study area

The study area is situated in Ikara, Local government area of Kaduna state, Nigeria. The area lies within the northern Nigerian Basement Complex between longitudes $08^0\ 00^{'}$ - $08^0\ 30^{'}$ E and Latitudes $11^0\ 00^{'}$- $11^0\ 30^{'}$ N as indicated in (Figs. 1 to 3). The area is in the Guinea Savannah climatic belt of Nigeria with distinct dry and wet seasons. Ikara area forms part of the northern Nigeria Basement Complex as shown in Fig. 2, and apart from an extensive superficial cover, the rocks in this area can be divided according to McCurry (1976) into:

- A crystalline complex of migmatite and gneisses probably of Dahomeyan age, including relicts of an ancient Birrimianmetasedimentry sequence,
- A younger metasedimentry series of Katangan age occupying north-south trending synclinal belts in the crystalline complex, and
- A suite of intrusive syntectonic to late tectonic granites and granodiorites of the late Precambrian to low
  Paleozoic age associated with extensive aplite and pegmatite development.

The rocks typically found within the Basement Complex include gneisses, migmatites, metasediments and some intercalation of amphibolites.

The crystalline Basement complex rocks are the oldest in the area, and they include both igneous and metamorphic types. The three divisions of the Basement rocks generally recognized in the area are the migmatite-gneiss complex, the meta-sedimentary rocks and the Older (or Pan African) granites. These rock units have been affected by many periods of orogenic movements resulting in extensive deformation and migmatization.

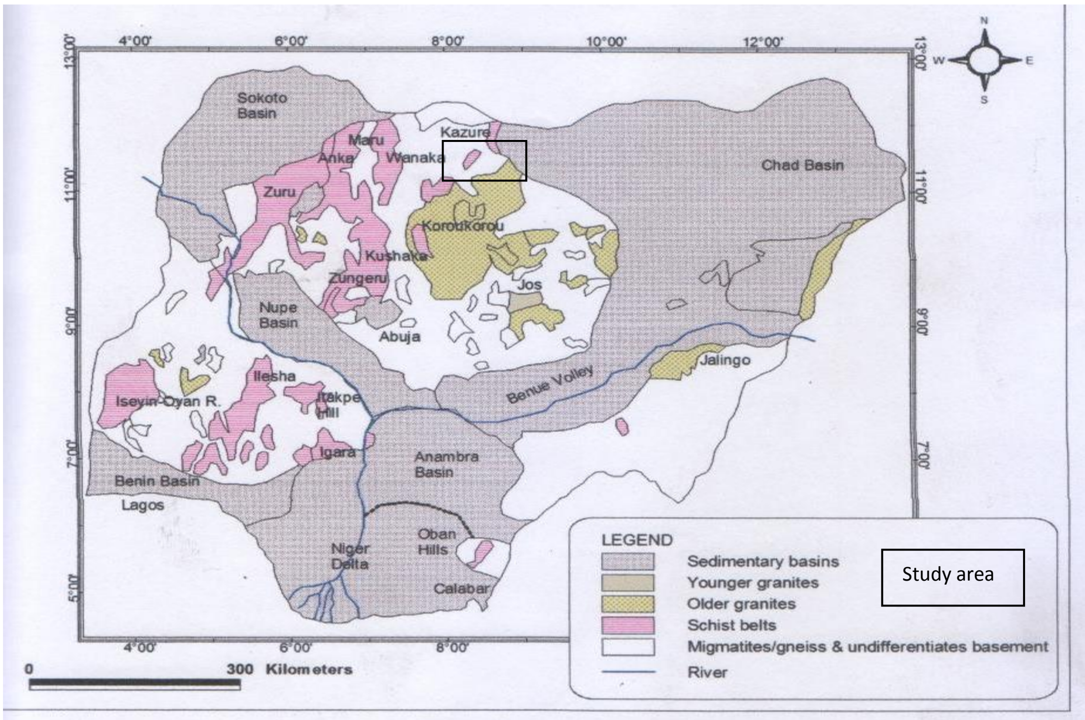

Fig. 1: Geological map showing the location of the study area modified after Woakes*et al.* (1987)

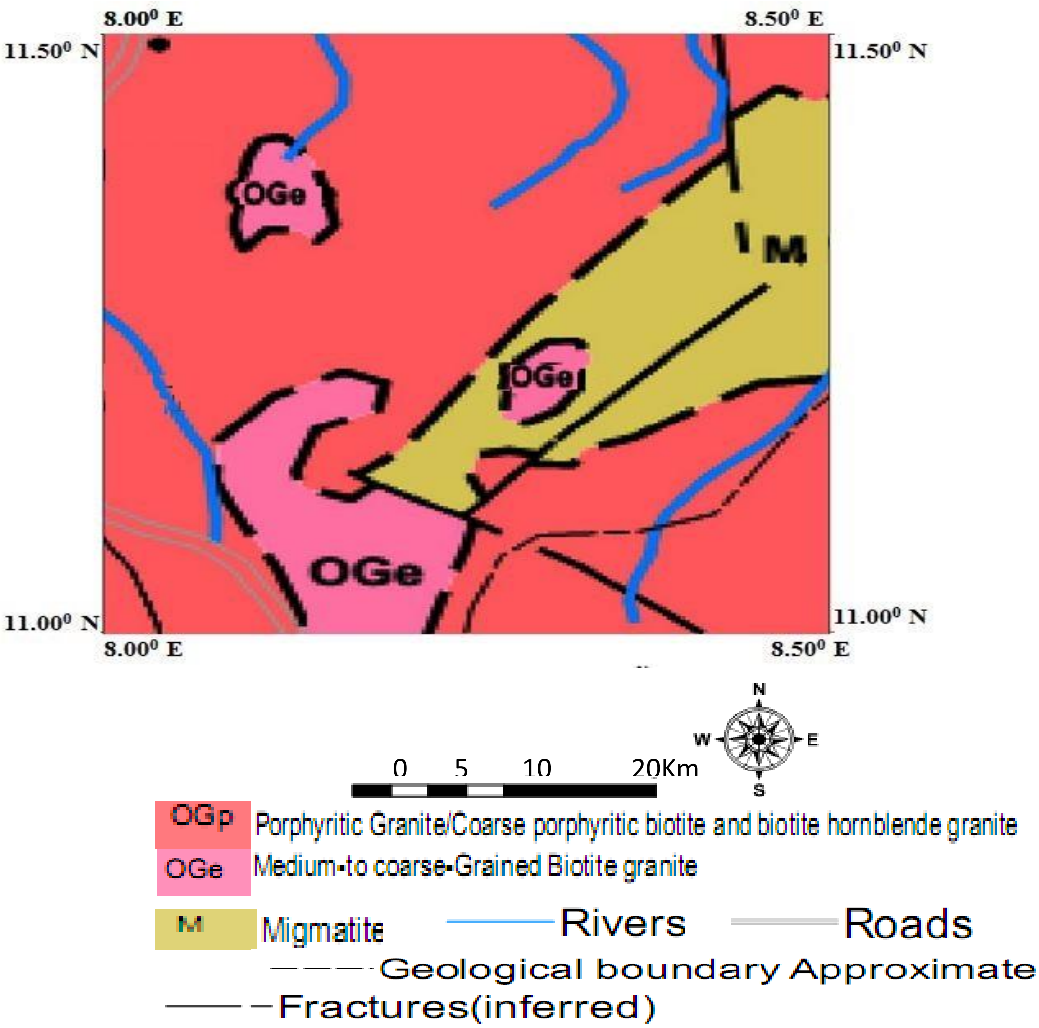

Fig. 2: Geological map of the study area afterNGSA (2012)

Materials and Methods

The data set used in this study is the High Resolution Aeromagnetic (HRAM) data of Ikara (Sheet 103) located between latitudes 11^0 00'N- 11^0 30'N and longitudes $08^0$00'E-$08^0$30'E, covers the study area and its environs. This was purchased from Nigerian Geologic Survey Agency (NGSA), Abuja. The map, which is on a scale of 1:100,000 and in half-degree sheet, was compiled from the data collected at a flight altitude of 80 m, along NE-SW flight lines spaced approximately 500 m apart. A regional correction was based on the International Geomagnetic Reference Field IGRF(2004). The magnetic field strengths in the study area range from 33101 to 32920 nT, with many structures trending in NE-SW directions (Fig.3). The arrow in the black rectangle indicates the position of the prominent granitic outcrop that houses amethyst mineralization veins. The high field strength values at the four corners of the map correspond to major outcrops in the area. These outcrops are majorly those of granitic rocks due to magnetite contents. But the suspected mineralization zone trends in the NW-SE direction, alongside minor anomalies corresponding to outcrops which are minor ones of the same rock type. Therefore, in order to derive improved information about the survey area and its vicinity, emphasis was laid on the effects of the geological contacts, critical for the structural framework of the area. The data processing involve accurate enhancement of short wavelength and linear features (aeromagnetic anomalies). In that regard, the aeromagnetic data were first re-gridded using a software, surfer v. 12 and subjected to regional/residual separation to isolate short wavelength signal from long wavelength signal, which is more suitable for better understanding of geology of the area of interest.

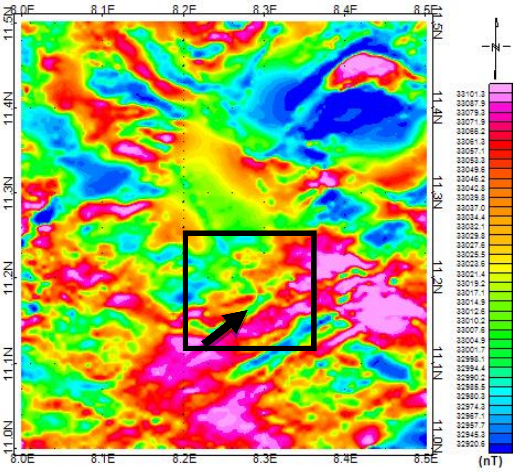

Fig. 3: Total intensity aeromagnetic map of the study area

Regional–residual separation

Magnetic data interpretation usually commences with some procedure that separates the smooth, presumable deep seated regional effects from the observed field so as to obtain the residual effects, which at times are the anomalies of geological interest. The regional magnetic fields are large features which generally show up as trends and continue smoothly over very considerable areas, and they are caused by deeper homogeneity of the earth's crusts (Nettleton, 1976).

The study area does not have a complex geology based on the geological setting, which are mainly Basement Complex rocks. Residual Field Aeromagnetic Anomaly Map (Fig.4) was extracted from the Total Field Aeromagnetic Anomaly Map (Fig.3) by a best-fit polynomial of first degree fitted to the aeromagnetic data set, using the least square technique. Residual magnetic field data set was obtained as the deviations of the fitted plane surface from the total magnetic field intensity (Megwara and Udensi, 2014). The field is characterized by values between -88.9 and 80 nT (Fig. 4). The patterns and structural trends of the residual anomaly and the total magnetic intensity fields are similar, with many structures trending in NE-SW directions. This is due to variability in the magnetite content of the granitic rock types in the area.

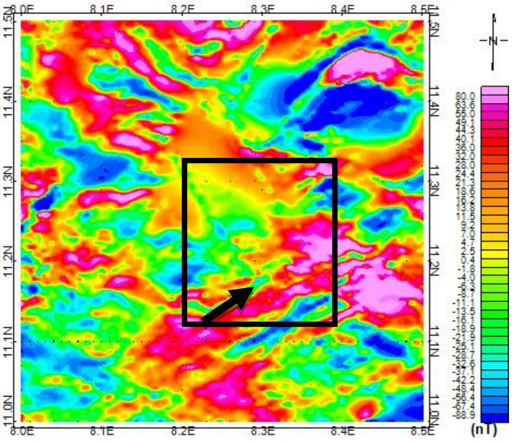

Fig. 4: Residual magnetic intensity map

First vertical derivative

Vertical gradients of potential fields are also a mainstay of the interpretation process, principally because they sharpen the response of geophysical features. This filtering method is effective in enhancing anomaly due to shallow sources; it narrows the width of anomalies and also very effective in locating source bodies more accurately (Cooper and Cowan, 2004). Derivatives tend to sharpen the edges of anomalies and enhance shallow features (Fig. 5). The vertical derivative map is much responsive to local influences than to broad or regional effects and therefore tends to give sharper picture than the map of the residual field intensity. Thus, the smaller anomalies are more readily apparent in area of strong regional disturbances. In fact, the FVD is used to delineate high frequency features more clearly where they are shadowed by large amplitude, low frequency anomalies.

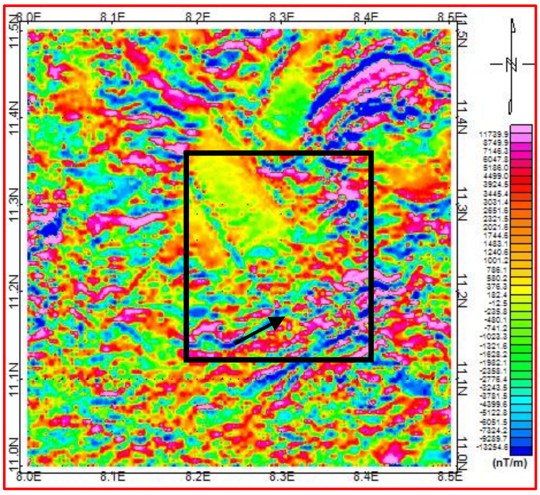

Fig. 5: First vertical derivative of the residual map

Analytic signal technique

Nabighian (1972) introduced the concept of the analytic signal for magnetic interpretation and showed that its amplitude yields a bell shaped function over each corner of a 2D body

with polygonal cross-section. For an isolated corner the maximum of bell-shaped curve is located exactly over the corner, and the width of the curve at half its maximum amplitude equals twice the depth to the corner. The determination of these parameters is not affected by the presence of remnant magnetization. Horizontal locations are usually well reliable by this method but depth determinations are only reliable for polyhedral bodies. In this work the amplitude of analytic signal in three-dimension was adopted.
The amplitude of the analytic signal in 3-D (Nabighian, 1972)is given by:

$$|A(x,y,z)| = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2} \qquad (1)$$

Where T is the magnetic anomaly field intensity, $\frac{\partial T}{\partial z}$ is the vertical derivative of the magnetic anomaly field intensity, $\frac{\partial T}{\partial x}$ and $\frac{\partial T}{\partial y}$ are the horizontal derivatives of the magnetic anomaly field intensity. The procedure for computing Amplitude of Analytic Signal in 3D is as follows: The magnetic anomaly field intensity value, T was computed along vertical direction (z-axis), i.e, $\frac{\partial T}{\partial z}$. The field value was also computed along two horizontal directions, $\frac{\partial T}{\partial x}$ and $\frac{\partial T}{\partial y}$ respectively. Then the absolute value of the amplitude for all the three derivatives was calculated using equation (1) and results displayed (Fig. 6). The location of the local mining for amethyst is shown by an arrow which is perpendicular to a conspicuous lineament (Fig.7), termed as a major lineament. This could probably serve as the conduit through which the mineral flows to the area of mining. Fig. 8 shows a contour map of the aeromagnetic data. It gives clear direction of the lineament of interest, produced with surfer software. The advantage of Analytic Signal method of magnetic data enhancement is that its amplitude function is always positive and does not need any assumption of the direction of body's magnetization Jeng*et al.*(2003). Peaks in the analytic signal amplitude can easily be located. Analytic signal can be used to detect the structures responsible for the observed magnetic anomalies over areas of interest.

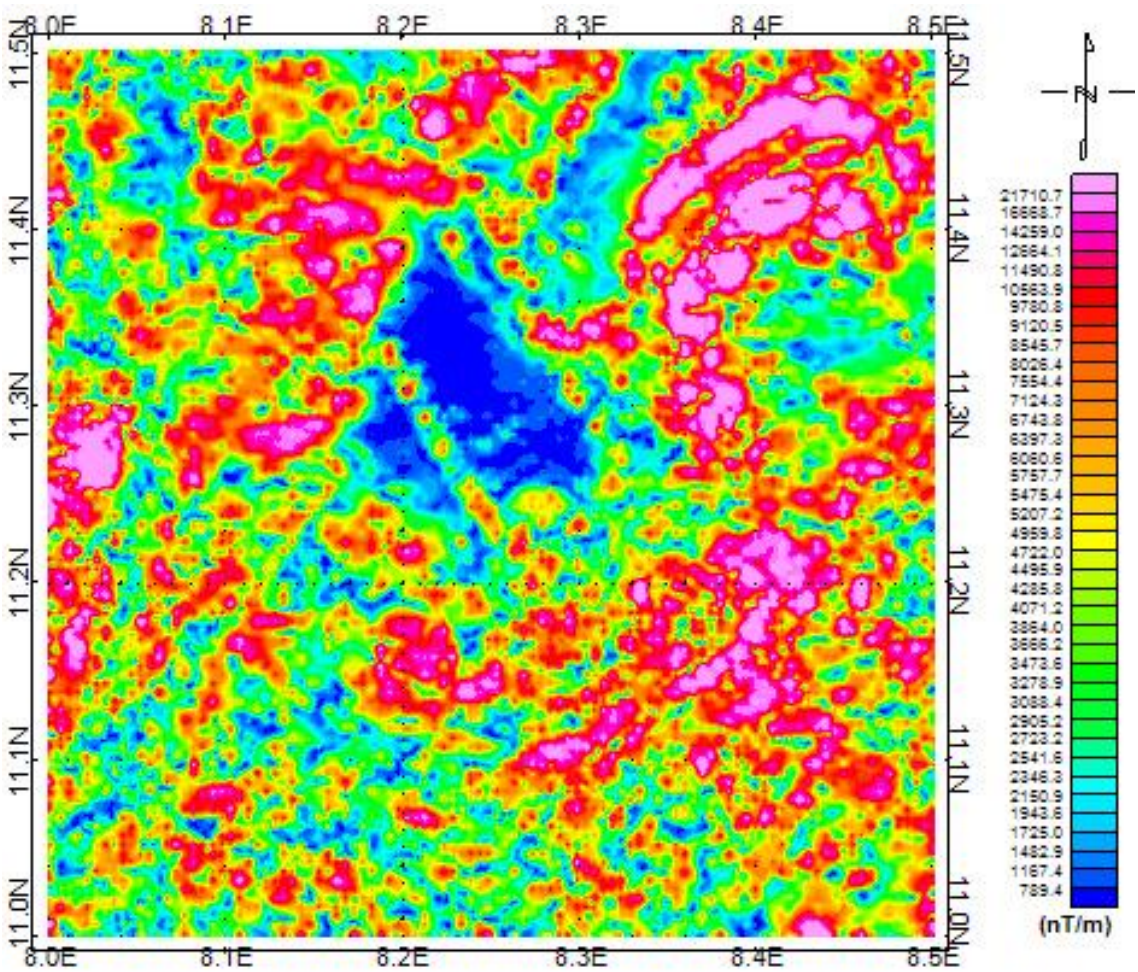

Fig. 6: Analytic signal of the Residual map of the study area

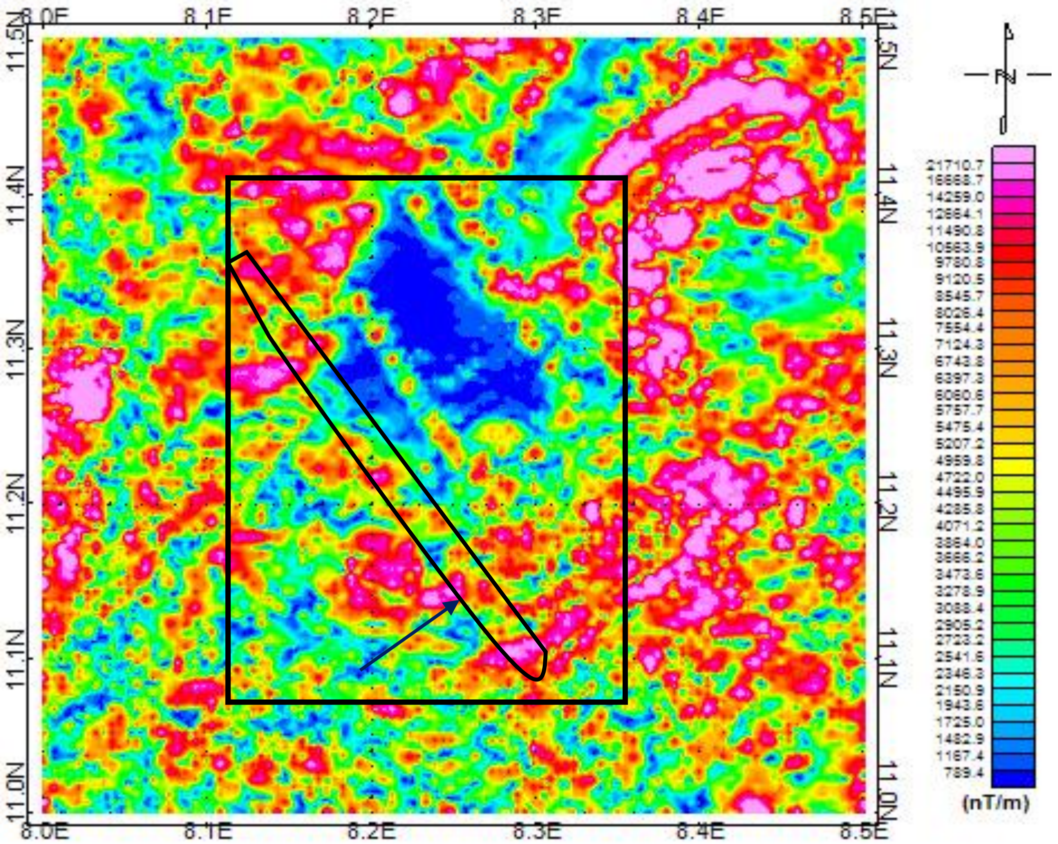

Fig. 7: Analytic signal of the Residual map of the study area showing trend of anomalous body perpendicular to the direction of amethyst mineralistion by an arrow

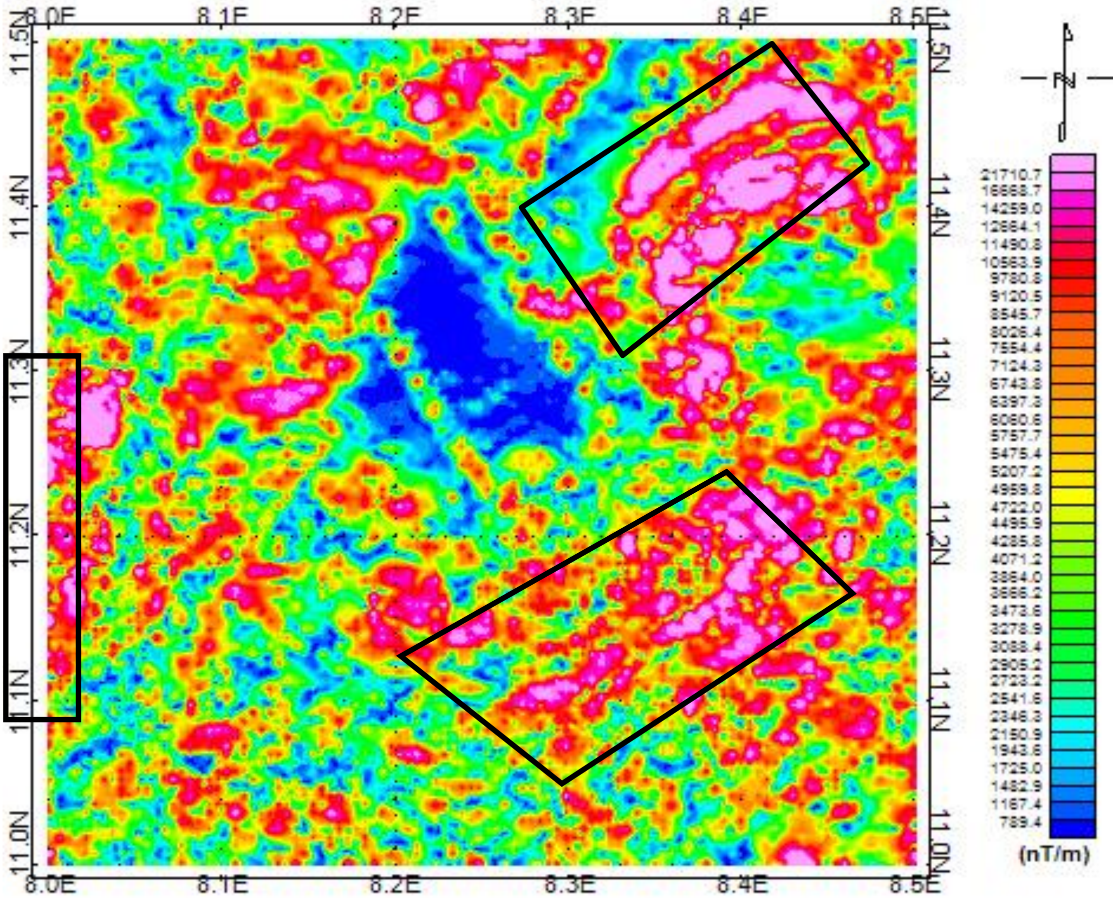

Fig 7: Analytic signal of the Residual map of the study area showing trends of anomalous bodies (minor lineaments)

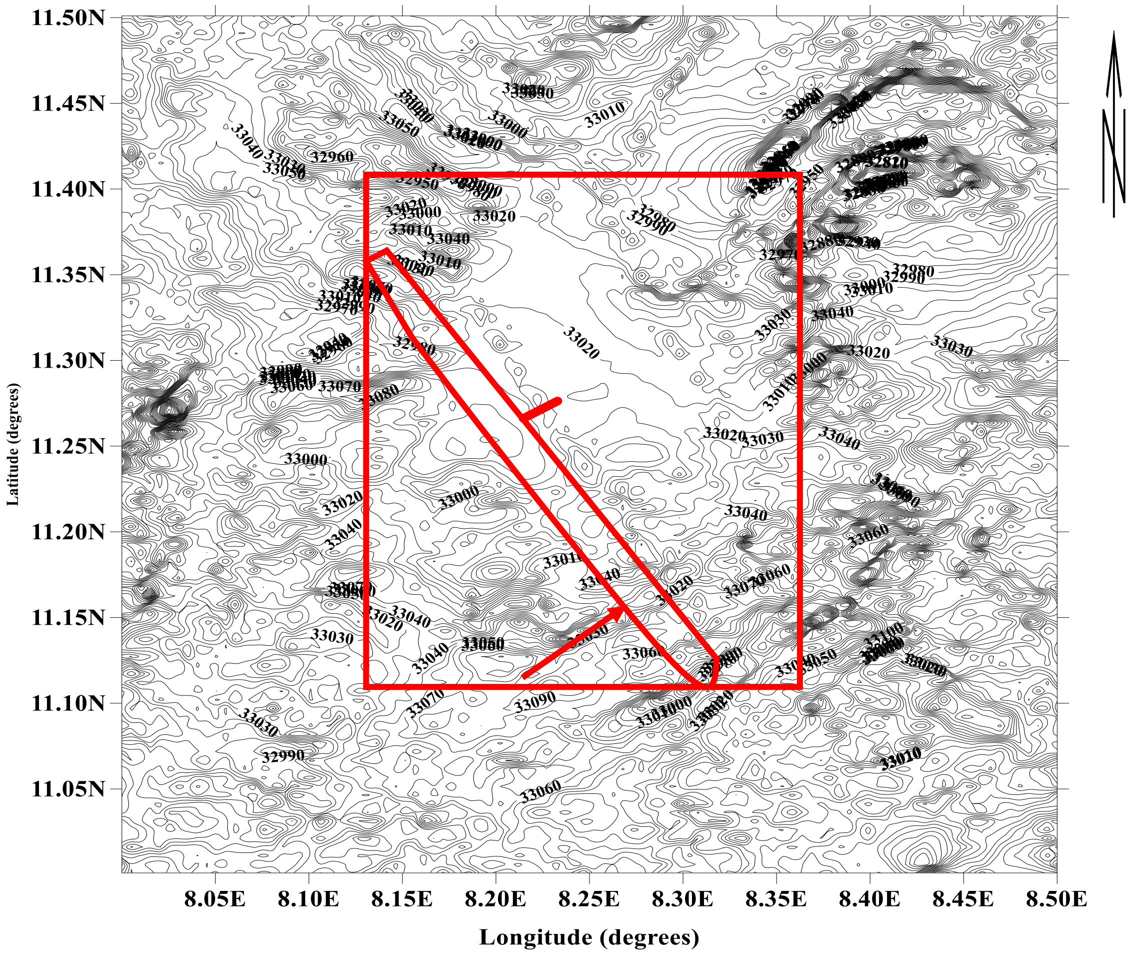

Fig. 8: Contour map of aeromagneticdata of the study for comparison with analytic signal map

Results and Discussion

The lineaments in Fig. 5 are classified into major and minor features. They are shallow structures and consist essentially rock-contacts due to variations in magnetite content in different rock types such as pegmatite, migmatite, biotite granite, porphyritic granite, biotite hornblende, and solidification of mineralizing fluids within rock-cracks. It was observed that there is presence of two (major) conspicuous lineaments cross-cutting a large number of smaller anomalies. These major lineaments are in the direction normal to that of the arrow shown inside a rectangle (Figs. 5, 6 and 8). The major lineaments which trend in the NW-SE and minor ones in the NE-SW, NNE-SSW, N-S directions (Figs. 5, 6, 7 and 8). These lineaments consist of essentially faults, fractures, joints, veins, etc. Since it is a well-known fact that local mining has been practiced in the area. This mineralization could be attributed to these geological structures, possible sources for trapping and migration of minerals, through concealed conduits within the earth. All the lineaments are therefore interpreted as belonging to fractures associated with major movements. Lineaments are identified through magnetic susceptibility contrasts and variations in magnetic field intensity values in geological strucures as stated earlier. Also intrusive and extrusive volcanic bodies either within basin or basement itself or variation of susceptibilities in materials within the basement (Behrendt and Klitgord, 1980). The origin of the causative mechanism for the geological strucures is attributed to tectonics activities (Alkali and Yusuf, 2010). The lineaments striking in the NNE - SSW direction probably represent zones of pegmatite and quartz veins (De Swart, 1953), which is in conformity with this study but adjacent to it, is amethyst vein established by the present study in the study area. This contrast is probably due to difference in rock compositions.

The analytic signal map in Fig. 6 shows distinct locations of the geologic structures along the conspicuous lineament in the study area and several smaller anomalies trending in the same directions as observed in the FVD. Only one conspicuous lineament appeared in the analytic signal map and and contour map (Fig. 8), in contrast to that in FVD map (Fig. 5). The lineament so pronounced could be attributed to high magnetic susceptibility materials within the basement (Behrendt and Klitgord, 1980). This lineament has maximum amplitude of about 21710.7 nT/m and minimum of 789.4 nT/m. The NNE - SSW lineaments probably represent the same trending fractures of the Nigerian Basement rocks described by Chukwu-Ike and Norman (1977); Oluyide (1988); Udoh (1988); Onyedim and Ocan (2001).

Conclusion

The study has demonstrated the importance of lineament mapping to evaluate the patterns and trends of geological features of a typical basement terrain involving the integration of Analytic and Derivatives techniques. The main results obtained in this study give an insight on the trends and magnetic field values of the geological structures (lineaments) of the study area. Filtering of magnetic data is used to enhance the data and to see features that would be difficult to detect without filtering. Application of selected filtering methods (FVD and AS) to the high resolution aeromagnetic data of the Ikara reveal trends of subsurface structures to be NE-SW, NNE – SSW, and N-S directions. The NE – SW linear structures belong to fractures associated with major movement produced by previous tectonic forces. The major lineaments/ anomalies in the basement trend NE- SW and NW-SE and are very likely associated to the Pan -African orogeny. All the lineaments are probably produced by ductile and brittle deformational events that affected the Nigerian basement rocks and hence, it is suggested that these zones be combed with detailed geophysical mapping for quantitative evaluation of the geologic structures in the area.

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