Interpretation of High Resolution Aeromagnetic Data of Part of Southwestern Nigeria for Subsurface Mapping

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Abstract
High resolution aeromagnetic data of part of southwestern Nigeria (Longitude 2° 40’ E and 5° 00’ E and Latitude 6° 00’ N and 8° 00’ N) were interpreted qualitatively and quantitatively. Vertical derivatives and analytic signal were employed in the qualitative interpretation with the aim of delineating geological structures (anomalies) and their trends. Euler deconvolution was employed in the quantitative interpretation which was aimed at determining depths to magnetic sources. The results of qualitative interpretation show high amplitude of the magnetic field intensity in the Basement Complex region and low amplitude in the Sedimentary Basin and some part of the Basement Complex that are associated with the schist. The directions of linear features delineated correlate with the geology of the study area. The trending patterns of the linear features are NE-SW, NW-SE and NNE-SSW. The NE-SW trending structures coincide with the structures from the Atlantic Ocean, the NNE-SSW structures provide a possible link to the Ifewara-Kalangai fault axis and the NW-SE trends could probably be due to the separation of the South American continent from Africa to accommodate the emerging Atlantic Ocean. The windowed Euler deconvolution solutions points coincide with regions having anomalies whose depths (<100 m - >9000 m) gave information about topography of the basement.

Keywords: Aeromagnetic data, Anomalies, Euler deconvolution, Geology and Interpretation

INTRODUCTION
Geophysical method is known to provide a relatively rapid and cost-effective means of obtaining information of the earth’s subsurface covering large areas. The method involves the use of various techniques which includes magnetic technique. Magnetic method is a geophysical survey technique that exploits differences in magnetic properties of minerals with the objective of characterising the earth’s subsurface. The technique requires the acquisition of measurements of amplitude of magnetic field at discrete points along survey lines that are distributed regularly throughout the area of interest.

Aeromagnetic data applications are well known in wide variety of geological studies and play an important role in tracing lithological contacts and for recognition of structures like faults, lineaments, dykes and layered complex (Reeves, 1990).
Several geological and geochemical studies have been carried in the southwestern region of Nigeria (Wright, 1976; Danbatta, 2008; Kolawole and Anifowose, 2011 and Akinmosin et al., 2013). The studies were mainly carried out because of the variety of rock types and the economic importance of some minerals that are associated with the rocks. Numerous geophysical studies have also been carried out (Ajakaiye et al., 1991; Adepelumi et al., 2008; Osinowo and Olayinka, 2013; Abraham et al., 2014; Osinowo et al., 2014 and Oladunjoye et al., 2016). The surveys on the other hand failed to provide information on the regional tectonic framework of southwestern Nigeria because the studies were on a local scale. The aim of this work is to identify and delineate subsurface structures within part of southwestern Nigeria by producing comprehensive structural maps of the study area which will improve information on the regional geology.

**GEOLOGY OF THE STUDY AREA**

The study area is underlain by rock groups of the crystalline Basement Complex of Precambrian to Cambrian age and Sedimentary rocks that are Cretaceous to Recent in age (Fig. 1).

**Crystalline Basement Complex**

The lithological units of crystalline Basement Complex are grouped as: Migmatite-Gneiss Complex, Metasedimentary/Metavolcanic Complex and Older Granite Series (Pan African). Migmatite-Gneiss Complex is composed of high grade metamorphic rocks. The gneisses and migmatites are intimately associated in the field. The migmatite is a group of rocks, made up essentially of gneisses and schist as paleosome and granitic rocks, pegmatite and aplite as neosome. The gneisses and migmatites are characterized by intricate folded and banded fabric complicated by quartzo-feldspathic intrusion and quartz rodding’s. Relicts of quartzite, marble and calc-silicate rocks occur within the migmatite-gneiss complex.

Metasedimentary/Metavolcanic Complex are referred to as supracrustal rocks believed to have been in folded into the basement of gneisses and migmatites. The schistose rocks consist of low to medium grade metamorphic rocks, composed of pelitic schist, quartz schist, banded iron formation, marble and calc-silicates plus subordinate amount of ultramafic rocks, amphibolites, metadiorites, and talc schist. Apart from the pelitic schists, psamitic rocks are abundant in the zone.

The Older Granite Series form the most conspicuous geomorphic features in the southwestern Nigeria, outcropping as batholiths, conical hills, thickly forested highlands. The Older Granites were emplaced in the Precambrian basement gneisses and metasediments. Lithologically, the Older Granites consist of coarse porphyritic biotite and biotite-hornblende granites, fine to medium-grained granites in addition to foliated and migmatitic types, syenites and granodiorites. However, the most widespread of the series are the coarse porphyritic types, which are characterized by large feldspar crystals (Rahman, 1988).
Fig.1: Geology map of the study area (adapted after NGSA, 2008).
The Sedimentary Rocks
The stratigraphy of the eastern Dahomey Basin has been discussed by many workers and several classification schemes have been proposed. These works include those of Jones and Hockey (1964); Ogbe (1972); Omatsola and Adegoke (1981); Coker et al. (1983); Billman (1992); Nton (2001); Elueze and Nton (2004); Nton et al. (2006) among others. Omatsola and Adegoke (1981) proposed the Cretaceous sequence in the eastern Dahomey Basin as beginning with the Abeokuta Group, made up of three formations from namely; the Ise, Afowo and Araromi Formations.

The Ise Formation unconformably overlies the Basement Complex of southwestern Nigeria and consists of conglomerate and grits at the base and in turn overlain by coarse to medium grained sands with interbedded kaolinite. Ironstones occur at some locations (Nton, 2001). The age is Neocomian to Albian.

Overlying the Ise Formation is the Afowo Formation, which is composed of coarse to medium grained sandstones with interbedded shales, siltstones and claystones. The sandy facies are tar-bearing while the shales are organic-rich (Enu, 1990). The lower part of this Formation is transitional with mixed brackish to marginal horizons that alternate with well sorted, sub-rounded sands indicating an estuarine near-shore environment of deposition. Billman (1992) assigned a Turonian age to the lower part of this Formation, while the upper part ranges into the Maastrichtian.

The Araromi Formation overlies the Afowo Formation and has been described as the youngest Cretaceous sediment in the Basin (Omatsola and Adegoke, 1981). It is composed of fine to medium grained sandstone with interbedded limestone, marl and lignite. The Formation contains abundant planktonic foraminifera, ostracods, pollen and spores. Omatsola and Adegoke (1981) assigned a Maastrichtian to Paleocene age to this Formation.

The Ewekoro Formation overlies the Araromi Formation in the eastern Dahomey Basin. It is an extensive limestone body which could be traced from Ghana in the west, to the eastern margin of the Dahomey Basin in Nigeria (Jones and Hockey, 1964). Elueze and Nton (2004) observed that the limestone is of shallow marine origin owing to abundance of coralline algae, gastropods, pelecypods, echinoid fragments and other skeletal debris. It is Paleocene in age.

Overlying the Ewekoro Formation is the Akinbo Formation, the Formation is made up of shale and clay sequence (Ogbe, 1972). The claystones are concretionary and are predominantly kaolinite (Nton and Elueze, 2004). The base of the Formation is defined by the presence of glauconitic band with lenses of limestone (Ogbe, 1972 and Nton, 2001). The Formation is Paleocene to Eocene in age.

The Ilaro Formation overlies the Oshosun Formation and consists of massive, poorly, consolidated, cross-bedded sandstones. The youngest stratigraphic sequence in the eastern Dahomey Basin is the Benin Formation. It is also known as the coastal plain sands (Jones and Hockey, 1964) and consists of poorly sorted sands with lenses of clays. The sands are in parts cross-bedded and show transitional to continental characteristics. The age is from Oligocene to Recent.
MATERIALS AND METHODS
High resolution aeromagnetic data of the study area sheets: 239, 240, 241, 242, 243, 259, 260, 261, 262, 263, 278, 279, 280, 281, 282, 278A, 279A, 280A, 281A and 296 were acquired from the Nigerian Geological survey Agency (NGSA) and processed using a suite of appropriate software. The data for each sheet, covers half-degree sheet were on a scale of 1:100000. The data were initially pre-processed by Fugro Airborne Survey and Consultant teams, pre-processing operation include micro leveling, removal of cultural effects as well as filtering for noise contents. Total magnetic intensity maps of the study area comprising of the sheets (Figs. 2) were plotted using the Oasis Montaj software (version 6.4.2). The missing data corresponding to the white portions is as a result of no survey being conducted at such areas. From Fig. 2, both long wavelength and short wavelength features are effectively displayed. The total magnetic field intensity ranges between 32923 and 33127 nT. A magnetic relief of 204 nT is attributed to differences in magnetic mineral content between various lithologies, and to the variation in the depth to magnetic rocks (Bird, 1997).

![Total magnetic field intensity map of the study area.](image)

The total magnetic field intensity gridded data of the study area were subjected to regional-residual separation in order to remove anomalies that are associated with low frequencies (Johnson, 1969 and Dobrin, 1976).

The residual aeromagnetic data were upward continued to a height of 2000 m (where the noise level of the second vertical derivative grid appears to be very low). This transformation highlights the longer spatial wavelength anomalies at the expense of the shorter wavelength anomalies (Fig. 3). In spite of the upward continuation, certain short wavelength anomalies were preserved, superimposed on regional anomalies. These anomalies have their origin in shallow geological structures.
Vertical derivatives

This technique uses potential field derivatives to suppress deep-seated long wavelength anomalies and to enhance field component that are associated with shallow features. It also resolves interference between adjacent anomalies. Mostly used for delineating near surface lineaments and contacts (Tarlowski et al., 1997). The first vertical derivative or vertical gradient can be thought of as component of the rate of change of the anomaly values as the potential-field data are upward continued.

The second vertical derivative is the vertical gradient of the first vertical derivative. First vertical derivative data have become an important tool in magnetic interpretations. Second vertical derivative has even more resolving power than the first vertical derivative, but its application requires high quality data because of its greater enhancement of noise (Fig. 4). It was shown by Hood and McClure (1965) that second vertical derivative is zero and rapidly changes sign at a point vertically over a contact. In magnetic data interpretation, second vertical derivatives are used to delineate the plain-view boundaries of intra-basement anomaly sources and are also found to be effective for enhancement of magnetic anomalies (Sharma, 2002). The zero-point (of the second vertical derivative) of the image map indicates the spatial locations of the magnetic source edges which in effect outline anomalous areas.

Analytic signal

The analytic signal or total gradient is formed through the combination of the horizontal and vertical gradients of the magnetic anomaly. It is based on the calculation of the first derivatives of magnetic anomalies to estimate source characteristics. This filter is applied to magnetic data and is aimed at simplifying the fact that magnetic bodies usually have a positive and negative
peak associated with it, which in many cases make it difficult to determine the exact location of the causal body.

![Second vertical derivative map of the study area.](image)

The analytic signal has a form over causative body that depends on the locations of the body (horizontal coordinate and depth) but not on its magnetization direction (Ansari and Alamdar, 2009). The amplitude of analytical signal was first developed by Nabighian (1972) in 2-dimensions and later extended to 3-dimensions (Nabighian, 1984 and Roest et al., 1992). The analytical signal modulus was applied to the total magnetic field anomaly (residual field data upward continued to 2000 m) data to produce the map (Fig. 5). This enhancement approach has been widely used as a tool in outlining geologic boundaries such as contacts and faults regardless of direction of magnetization. The amplitude of the analytic signal shows maxima over boundaries/edges.
Euler deconvolution

Euler’s homogeneity relation has attracted interest from geophysicists over the years because it serves as a fast means of processing a magnetic gridded data to derive trends and depth estimates in an automatic or semiautomatic manner (Reid et al., 1990). Thompson (1982) suggests that a 3-D implementation of EULDPH algorithm could be used to analyse mapped magnetic data. This methodology utilizes the total potential field and its related gradients (X, Y, and Z components) to derive the rate of change of potential field with respect to distance from the source location and depth. The degree of homogeneity of the rate of change of the three gradient components is directly related to geometry of the source body and is commonly referred to as the structural index (Thompson, 1982).

Processed aeromagnetic data were subjected to Euler’s deconvolution operation to determine depths to magnetic sources as done by Thompson (1982); Reid et al. (1990); Mushayandebvu et al. (2001) and Hsu et al. (2002). The standard Euler deconvolution method was employed. The standard method examined all grid locations and retained only those locations with valid solutions. Results of the standard Euler deconvolution method were compared and the closest solution to the geologic model was accepted.

Filtered aeromagnetic data (residual magnetic field data upward continued to 2000 m) were used as the starting grid for the Euler deconvolution because of its relatively high signal to noise ratio. Euler deconvolution processing parameters such as structural index, maximum % depth of tolerance, window size and maximum distance were carefully selected to improve the integrity of the solution results from the study area. However, Euler deconvolution has been successfully used in Basement Complex environments for mineral exploration and other investigations (Cooper, 2008), as well as used with high degree of precision in near surface investigation for locating unexploded ordinance.
Structural indices values of 0.0 and 1.0 were used based on the assumed geological models of the source to be individual contacts or dykes/sills. The obtained solutions were further refined by using windowing technique in order to reduce uncertainty to the barest minimum (Figs. 6a - d).

Fig. 6a: Euler deconvolution solution plots of the study area (N = 0.0).

Fig. 6b: Euler deconvolution solution plots of the study area (N = 1.0).
RESULTS AND DISCUSSION

Visual studies of total magnetic field intensity and upward continued maps of the study area revealed variations in magnetic field intensity. The observations made on total magnetic field intensity map is more visible on the upward continued map because the data has been enhanced.
Regions of magnetic lows (low amplitude magnetic values) and highs (high amplitude values) are apparent on the upward continued maps. The anomalies characterised by low values of magnetic intensity range from about -77 to 0 nT and the magnetic highs range from 2 to 52 nT. The sharp contrast is enhanced due to sharp magnetic intensity contrast between the crystalline and the sedimentary rocks magnetic susceptibilities. The prominent high amplitude magnetic intensities noticeable on the upward continued magnetic intensity maps trend mostly in NE-SW and NW-SE directions. High amplitude magnetic values correspond to region with high magnetic mineral contents which in the study area correspond to the Pre-Cambrian to Pan-African Crystalline Basement rocks of the southwestern Nigeria. The low amplitude magnetic values trend in W-E, NNE-SSW and NW-SE. Low amplitude anomalies also characterised in the southern part of the mapped area as well as in some parts of northeast and northwest. Many of these regions coincide with areas with thin to relatively thick sedimentary cover, where the effect of the thick clastic materials of weak magnetic susceptible masks the high magnetic susceptibility originating from relatively deep basement rocks.

Residual magnetic field intensity map upward continued to a height of 2000 m shows that besides the obvious long wavelength anomalies, short wavelength anomalies are essentially enhanced. The NE-SW direction is in conformity with the suspected structures coming from the Atlantic Ocean, the NNE-SSW trending structures provide a possible link to the Ifewara-Kalangai fault axis, and the NW-SE trends could probably be due to the separation of the South American continent from Africa to accommodate the emerging Atlantic Ocean.

Further enhancements of the short wavelength anomalies trends in the data set are achieved in the first and second vertical derivatives as well as analytic signal of the upward continued magnetic intensity grid. Systems of negative trending anomalies of short wavelength which are rimmed by positive anomalies are clearly visible. The boundaries in the second vertical derivative map clearly shows an inward extension of the Sedimentary Basin. The windowed Euler deconvolution solution points coincide with regions having anomalies whose Euler depth (<100 m - >9000 m) gave useful information about the topography of the basement. The NE-SW structure in the northwestern part of Fig. 6c (Euler deconvolution solution plots for contact superimposed on the second vertical derivative map) could probably be a deep seated rift or valley given that it did not appear well on the geologic map.

**CONCLUSION**

In this research, high resolution aeromagnetic data have been used to investigate the presence of anomalies in the study area. Both qualitative and quantitative interpretation techniques were chosen to achieve the outlined objectives of this research.

The results of the qualitative techniques yield high magnetic amplitude in the Basement Complex region and low amplitude in the Sedimentary Basin and some part of Basement Complex associated with schist. The high magnetic intensity is believed to be due to the presence of hematite and magnetite in the rocks. The direction of linear features delineated correlates with the geology of the study area. The trending patterns of the linear features are NE-SW, NW-SE, and NNE-SSW.
The windowed Euler deconvolution solutions points coincide with regions having anomalies whose depths (<100 m - >9000 m) gave useful information about the topography of the basement.
REFERENCES


