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Source Depth Determination from Aeromagnetic Data of Ilesha, Southwest Nigeria, Using the Peters' Half Slope Method

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Abstract

The slope method is one of the earliest magnetic depth estimate techniques which can determine the depth to the top of magnetic basement. Reduction-to-pole was applied to the aeromagnetic data of Ilesha southwest, Nigeria with sheet number 243. The data which was originally partitioned into different profiles was later processed to generate reduction-to-pole graph. The contour map of the study area was partitioned into four quadrants, with the highest magnetic anomaly occurring at the third quadrant (southwest region), while the northwest region has the lowest magnetic anomaly. The depth to top for very thin body, intermediate body and very thick body was determined using the Peter's half slope method. These values range between 2.40 km and 10.60 km for the very thin body, 1.8 km to 7.93 km for the intermediate body and 1.41 km to 6.35 km for the very thick body. These results revealed the extent of the depth of the source of the magnetic anomaly that was produced by the aeromagnetic data of the study area.

Keywords: Ilesha, aeromagnetic data, half-slope method, magnetic anomaly

1. Introduction

Magnetic method is one of the best geographical techniques to delineate subsurface structures. Generally, aeromagnetic maps reflect the variations in the magnetic field of the earth. These variations are related to changes of structures, magnetic susceptibilities and/or remnant magnetization. Sedimentary rocks, in general, have low magnetic properties compared with igneous and metamorphic rock that tend to have a much greater magnetic content. Thus, most aeromagnetic surveys are useful to map structure of the basement and intruded igneous bodies from basemen complex (Essam et al., 2003).

Airborne geophysical survey reflects the variations in the distribution and type of magnetic Mineral below the earth surface (Nabigbian et al., 2005). The area under study, shown in Figure 1, is Ilesha in Osun state, southwestern part of Nigeria.

The airborne survey of the study area was carried out by Nigeria Geological Survey Agency. The data was acquired along parallel flight line oriented in a NW - SE direction at 500 m flight line spacing, while the tie lines are spaced at 2 km directed to NE - SE direction. Figure 3 shows the total magnetic intensity plot of the aeromagnetic map used in this study, extended between N 7°37'0" and N 7°39'57" of latitude and from longitude E 4°44'0" to E 4°46'37" in Osun State Nigeria.

This paper attempts to remotely map the Precambrian basement structure using regional aeromagnetic survey data. Aeromagnetic data allow fast coverage of large and inaccessible area for subsurface reconnaissance, which makes magnetic data analysis an essential tools for geophysical exploration. The processing of these data can provide important evidence for regional-scale basement faulting in Ilesha, southwest Nigeria.

This study deals with interpretation of the observed aeromagnetic data of Ilesha area. Such interpretation is based on application of Reduction-To-Pole and Peter's Half Slope methods. The principal objective is to determine the depth to the top of the magnetic anomalies.

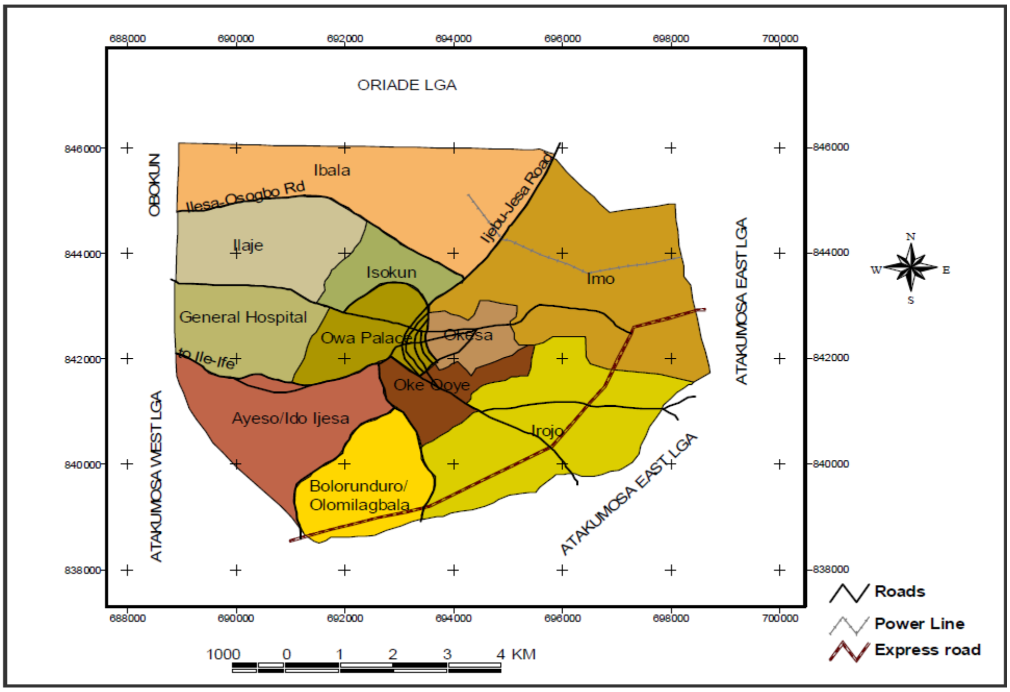


Figure 1. Map of Ilesha, the study area

1.1 Local Geology Setting

The geology of Ilesha area, shown in Figure 2, consists of Precambrian rocks that are typical for the basement complex of Nigeria (Rahaman, 1976). The major rock associated with Ilesha area form part of the Proterozoic schist belt of Nigeria which is predominantly developed in the western half of the country. In terms of structural features, lithology and mineralization, the schist belts of Nigeria show considerable similarities to the Achaean Green Stone Belts (Kehinde-Philips & Gerd, 1995; Ajayi, 1981; Rahaman, 1976).

The rocks of the Ilesha district may be broadly grouped into gneiss-migmatite complex, mafic-ultra mafic suite (or amphibolites complex), meta-sedimentary assemblages and intrusive suit of granitic rocks. A variety of minor rock types are also related to these units. The gneiss-migmatite complex comprises migmatic and granitic, calcerous and granulitic rocks. The mafic-untramafic suite is composed of amphibolites, amphibole schists and minor meta-ultramafites, made up of authophillite-tremolite-chlorites and talc schist. The meta-sedimentary assemblages, chiefly metapelites and psamitic units are found as quartzites and quarter schist. The intrusive suite consists essentially of Pan African granitic units.

Rocks in Ilesha schist belt are structurally divided into two main segments belt as the major fracture zones usually called Iwaraja faults in the eastern part and the Ifewara faults in the Western part of Ilesha (Kayode, 2009; Folami, 1992; Elueze, 1986).

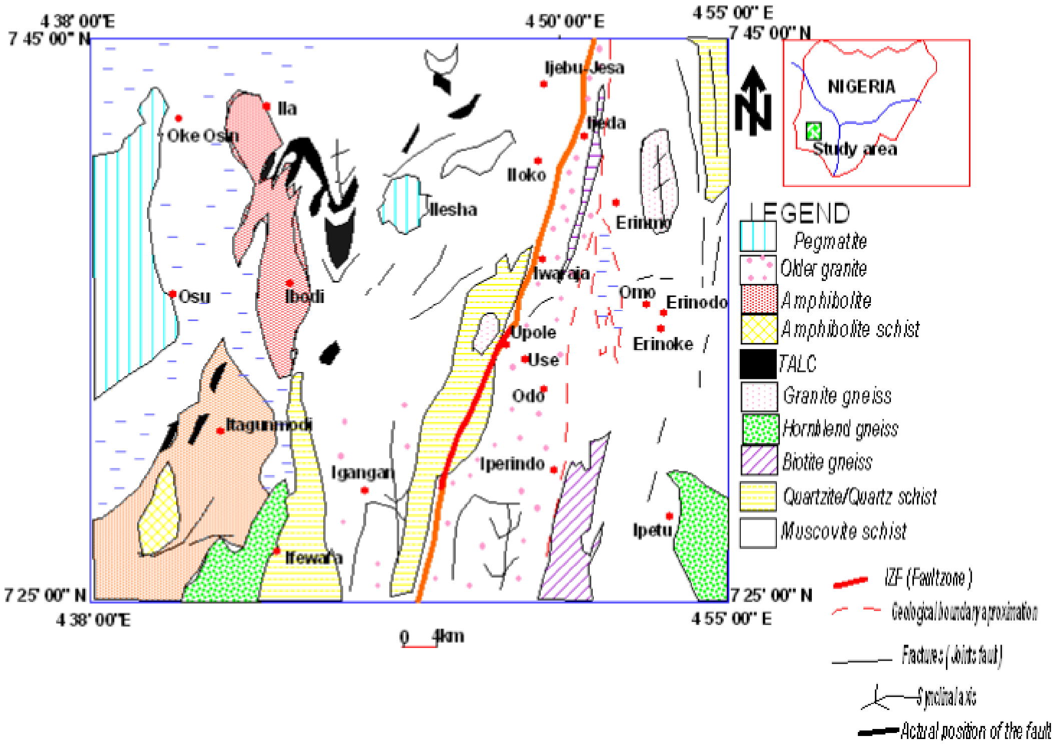


Figure 2. Generalized geological map of Ilesha schist belt southwest Nigeria (After Elueze, 1986)

Ansari and Alamdar (2009) uses analytic signal was as reduction pole operator and applied it on the synthetic magnetic data and on the real magnetic data from an area in shahrood region of Iran. The result show that least difference is relevant to the causative body location and the analytic signal can be used as substituent method for conventional RTP.

Kayode et al. (2010) focused on fault delineation when performing the ground magnetic study of Ilesha East. Southwestern Nigeria.

Ram et al. (2007) wrote a note on the qualitative appraisal of aeromagnetic image of Chhattisgarh basin. He used the aeromagnetic map of the area to extract the geologic information from the mapped and image the anomalies in a systematic way.

2. Method

Aeromagnetic survey of Ilesha area was conducted by Nigeria Geological Survey Agency. This Survey was carried out along a set of parallel flight lines at 500 m spacing and oriented in a NW - SE direction. The data were recorded at a sampling interval of 100 m. The tie lines are spaced at 2 km directed to NE - SE direction.

The recorded magnetic anomalies display several trends. It should be stated that magnetic trends do not occur at random, but are generally aligned along definite and preferred axes forming trends that can be used to define magnetic provinces (Affleck, 1963; Hall, 1979).

The total magnetic intensity (TMI) contour map of Ilesha area in Figure 3 shows positive and negative magnetic anomalies, which are distributed throughout the area. Maximum magnetic value (120 nT) was recorded at the southwestern part and the minimum value (-80 nT) was recorded majorly at the Western part Northwest.

Aeromagnetic surveys were flown with a flight height of 100 m and a nominal flight line spacing of 500 m. The International Geomagnetic Reference Field (IGRF) value used for correction is 32893,7334 nT. The inclination and declination angles of the ambient field were taken as -9.45^{o} and -2.95^{o} respectively.

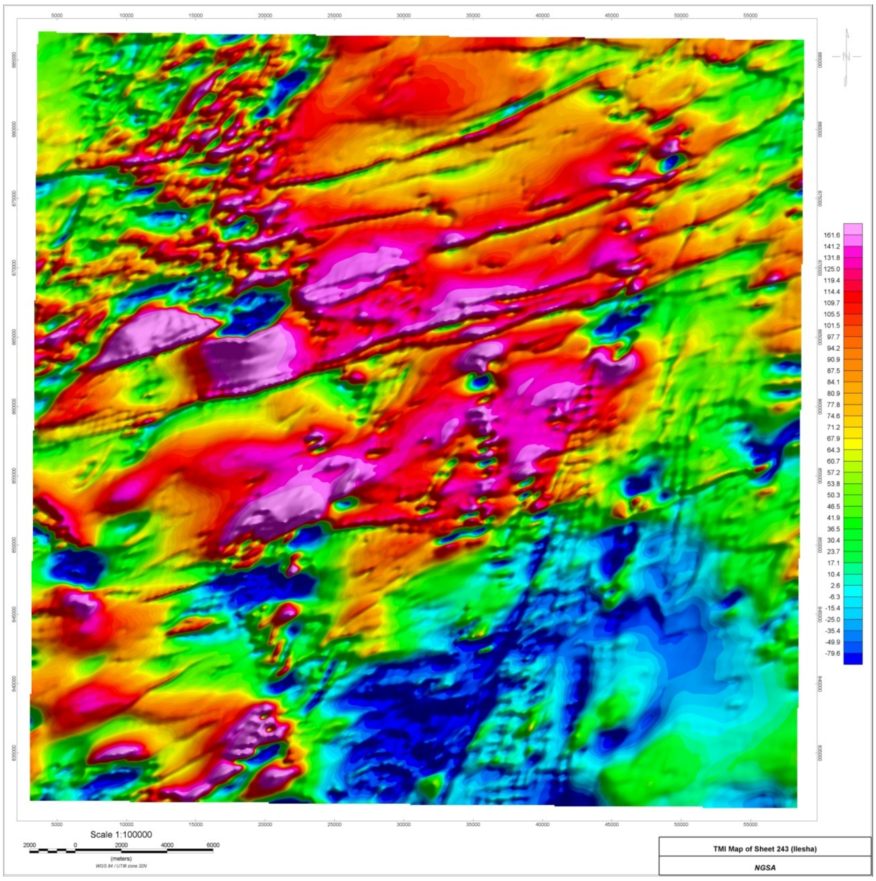


Figure 3. Total magnetic intensity map

2.1 Reduction to the Pole

The goal of reduction to the pole is to take an observed total magnetic field map and produce a magnetic map that would result to an area being surveyed at the magnetic pole. Assuming that all the observed magnetic field of the study area is due to induced magnetic effects, pole reduction can be calculated in the frequency domain using the following operator (Grant & Dodds, 1972).

$$L(\theta) = \frac{1}{\sin(I)\cos(I)\cos(D-\theta)^2} \quad (1)$$

where,

θ is the wave number;

I is the magnetic inclination;

D is the magnetic declination.

In reduction to the pole procedure, the measured total field anomaly is transformed into the vertical component of the field caused by the same source distribution magnetized in the vertical direction. The acquired anomaly is therefore the one that would be measured at the North magnetic pole, where induced magnetization and ambient field both are directed downwards (Blackely, 1995).

2.2 Peter's Half Slope Method

The slope method is one of the earliest magnetic depth estimate techniques. Peter's half slope method (Peters, 1949) estimates depth by finding the horizontal distance between two parallel lines that pass through the maximum and minimum of an anomaly and have a slope equal to one half of the maximum horizontal gradient of the anomaly. The depth (h) to the top of the body has reduction to-pole applied, is given as:

$$P = kh \quad (2)$$

P is the horizontal distance between two parallel lines while *k* is a constant. When *k* is equal to 1.20, the body is said to be very thin, if *k* is equal to 1.60, the body is said to be intermediate and when the value of *k* is 2.0, we have a very thick body. These values have been calculated for the study area and presented in Table 1

Table 1. Peter's half slope results

PROFILES	DEPTH. P (km)	VERY THIN BODY (km)	INTERMIDIATE THICKNESS (km)	VERY THICK BODY (km)
A	5.30	4.40	3.30	2.60
B	4.60	3.80	2.70	2.30
C	10.90	9.10	6.80	5.50
D	5.80	4.80	3.60	2.90
E	8.10	6.80	5.10	4.10
F	4.20	3.50	2.60	2.10
G	8.80	7.30	5.50	4.40
H	12.70	10.60	7.90	6.30
I	11.60	9.70	7.30	5.80
J	6.70	5.60	4.20	3.30
K	5.30	4.40	3.30	2.60
L	6.70	5.60	4.20	3.30
M	2.80	2.40	1.80	1.40
N	9.50	7.90	6.00	4.80
O	4.90	4.10	3.10	2.50
P	8.80	7.30	5.50	4.40
Q	11.30	9.40	7.10	5.60
R	6.70	5.60	4.20	3.30
S	8.60	7.20	5.40	4.30
T	7.90	6.60	5.50	4.00
AVERAGE		**6.310**	**4.730**	**3.790**

3. Result and Discussion

In this work, the reduction to pole (RTP) is applied to the profile data of Total magnetic intensity TMI of Ilesha. RTP corrects the shift between the source and magnetic anomalies due to the non-vertically of both normal field and the magnetization. The geophysical data for the different profiles were analyzed using software developed by G. R. J Cooper (Sign Proc), after which manual determination of depth to the top was calculated from reduction to pole graphs (Figure 6) using Peter's half slope formula.

The depth to the top of the body is proportional to the horizontal distance. The proportionality factor varies from 1:2 for very thick bodies (Table 1). The depth estimated is very deep since the total magnetic field which was later reduced-to-pole is used and thereby renders the depth estimated for thin body very accurate (1:1.2).

The application of Peter's half slope method to the magnetic data of the study area reveals the depth of subsurface structures at different profiles. The values of depth (h) to the top of the body have been calculated for different values of constant *k* and the result is presented in Table 1.

The thin magnetic body D1 has an average depth of 6,310 km while the thick magnetic body D3 has an average depth of 3,786 km. The thin magnetic anomaly is as a result of basement rocks which intruded into the sedimentary rocks while the deeper magnetic anomaly is associated with intra-basement discontinuities like faults. The average sedimentary thickness of 3,786 km estimated in the study area is favorable for hydrocarbon generation. Table 2 shows the variation of structural depth of aeromagnetic data of the study area.

Table 2. Variation of structural depth of aeromagnetic data of some part of Ilesha

STRUCTURAL DEPTH	MINIMUM DEPTH (km)	MAXIMUM DEPTH (km)	AVERAGE DEPTH (km)
D1	2.400	10.600	6.310
D2	1.800	7.930	4.732
D3	1.410	6.350	3.786

The estimated depths to magnetic basement are shown as D1, D2, and D3 (Table 2). The first segment D1 is the depth to the top for very thin body. The segment varies from 2.4 km to 10.60 km with an average of 6,310 km. The second layer depth D2 varies from 1.80 km to 7.93 km, with an average of 4,732 km. The third layer depth D3 varies from 1.41 km to 6.36 km, with an average of 3,786 km. The total magnetic intensity or basement depth (sedimentary thick body) contour map of the study area is shown in Figure 3.

The contour map of the study area is shown on Figure 4. It shows that the area is composed of four quadrants or regions; northeast, northwest, southeast and southwest. The regions can be distinguished on the basis of the variations in anomaly signatures of the contour lines, which reflect the variation of intensity of magnetic response. The northeast is characterized by low magnetic anomaly while the southwest quadrant of the contour map reflects a very high anomaly. Maximum magnetic value (120 nT) was recorded at the southwestern part and the minimum value (-80 nT) was recorded majorly at the Western part Northwest.

A 3-D surface map of the study area is depicted in Figure 5. The areas with great spikes indicate high magnetic intensity.

Two profiles (for want of space) of the reduction to the pole graphs are shown in Figure 6, from where the Peter’s half-slope formula was applied to obtain the various depths.

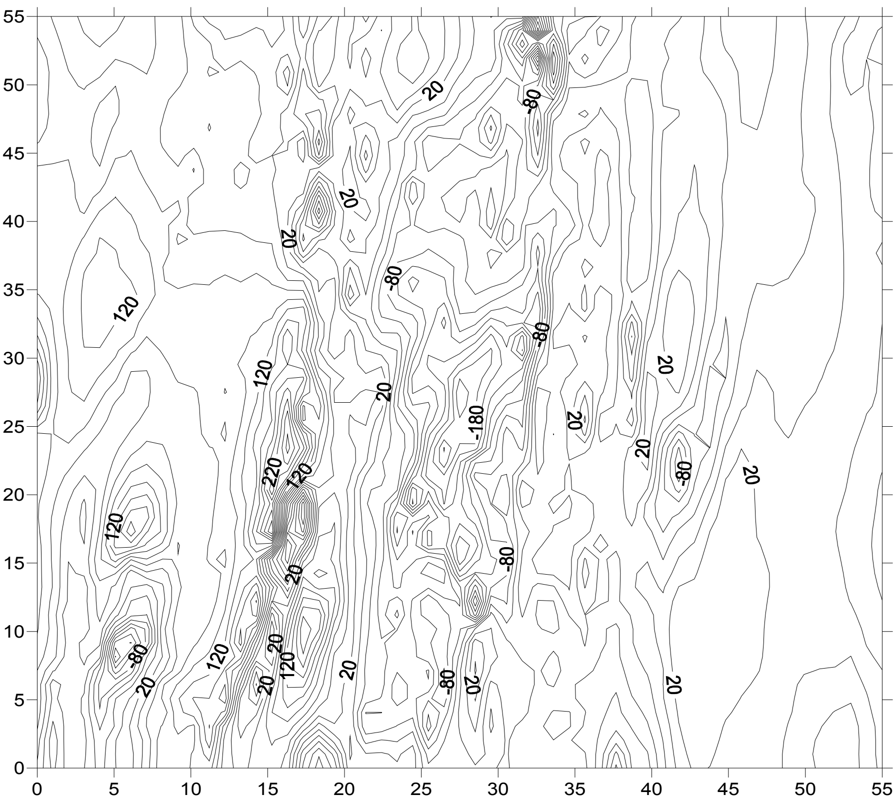


Figure 4. Contour map of the study area

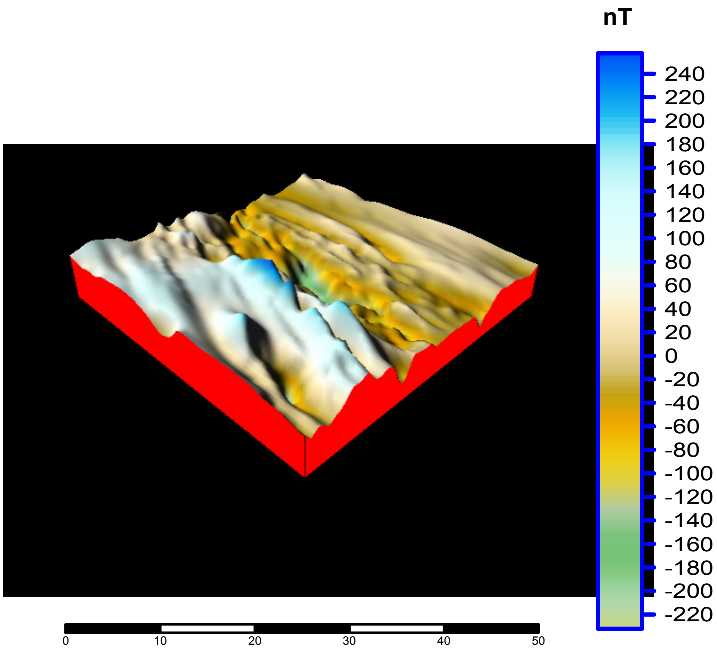
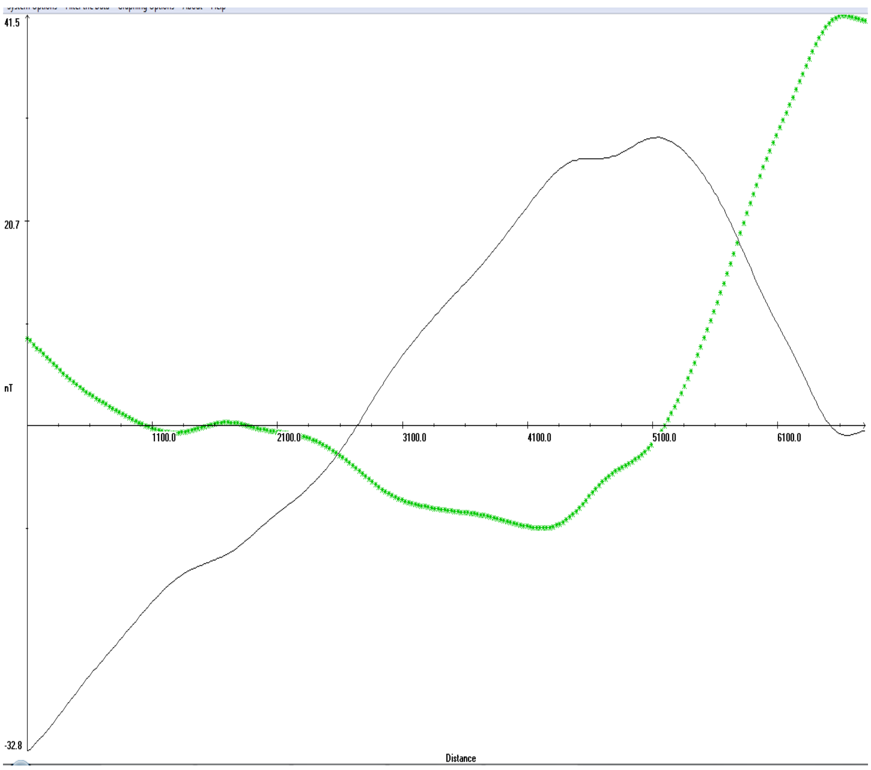


Figure 5. Surface map of the study area

Profile A



Profile B

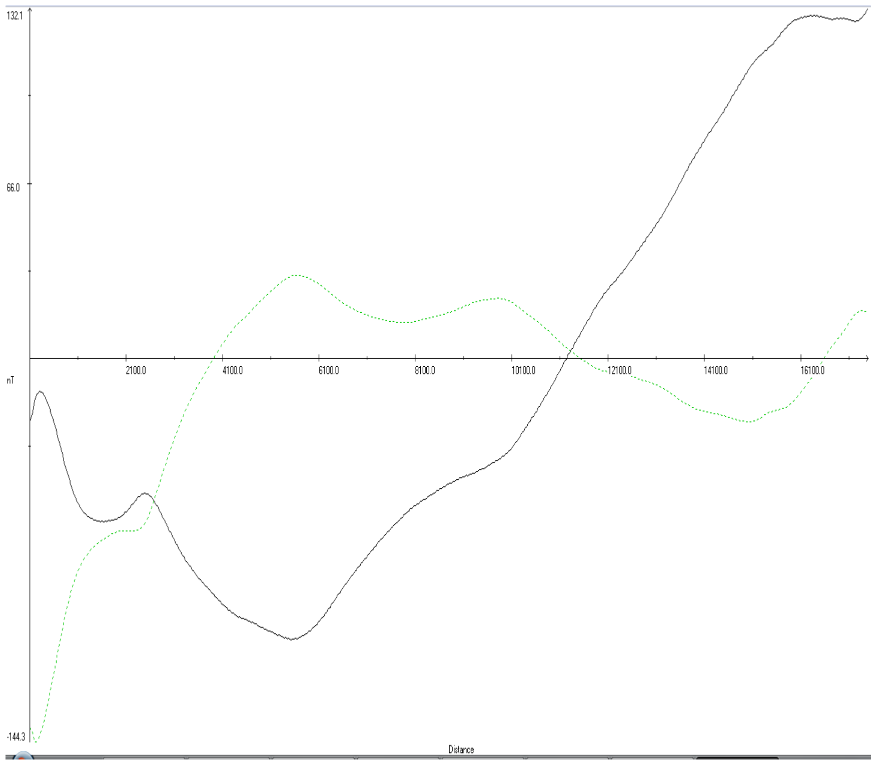


Figure 6. Reduction to pole graphs

4. Conclusion

- Reduction-To-Pole and Peter's half slope method were applies to airborne magnetic data of some part of Ilesha southwestern Nigeria to determine the depth of the magnetic source edges as an aid to structural interpretation. Reduction-To-Pole method corrects the shift between the source and magnetic anomalies due to non-verticality of both normal field and the magnetization.
- Maximum magnetic value (120 nT) was recorded at the southwestern part and the minimum value (-80 nT) was recorded majorly at the part Northwestern part, according to the contour map as depicted in Figure 4.
- Peter's half slope estimated the depth by finding the horizontal distance between the two parallel lines that passes through the maximum and minimum of an anomaly.
- Average depths of 6,310 km, 4,732 km and 3,786 km were determined for the respective segments D1, D2 and D3.
- Depth to the top interpretation of aeromagnetic field data provided important information on basic architecture for petroleum exploration and for mapping areas where basement is thin enough for mineral exploration. Magnetic basement is an assemblage of rocks that underlines sedimentary basins and may also outcrops in places. Onyedim et al. (2006) believes that if the magnetic units in the basement occur at the basement surface, then depth determinations for these will map the basin floor morphology and its structure appropriately.

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