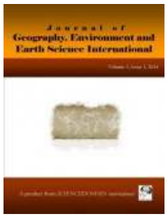

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Geomagnetic Signature and Depth Estimate of Basement Rock around Iseyin Area (Ado-Awaiye), Ibadan, Southwestern Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Authors IA and AHA carried out the geomagnetic survey, data analysis and qualitative interpretation. Authors IA and AIJB carried out literature review and detailed quantitative interpretation. Author IA finally prepared the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Ground geomagnetic survey was conducted around Iseyin Area, part of Ado-Awaiye in order to map and ascertain the nature of variability in the magnetic signature of the subsurface rock, structure of the magnetic basement as well as the depth to basement top. This was aimed at revealing the subsurface basement configuration, lithology and its mineralization.
Total field intensity were measured and recorded at each station with the value of the magnetic anomaly ranging from 30446.47 nT to 33536.10 nT (nanotesla). Regional-residual separation and half - width methods were applied and after necessary data processing, the results were presented in form of magnetic map and profiles.
Qualitative and quantitative interpretations were made based on the maps and profiles. Variation in the magnetic data reveals variation in the basement lithology with the higher value corresponding probably to the amphibolite (basic) component and the lower value corresponding to the granitic or

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gneissic component of the migmatite-gneiss (the area is underlain by migmatite-gneiss as revealed by surface outcrop). The magnetic character and signature varies being higher at the west and lower at the east. The result also reveals that the magnetic basement is shallow (2.5 m) at some places and relatively deep (22.0 m) at some other places with few basement lineament, suprabasement block and intrabasement block (basement depression). The lineament and intrabasement block can be exploited for groundwater development.

Keywords: Ground geomagnetic; Ado-Awaiye; magnetic anomaly; half-width; depth to basement top; magnetic basement.

1. INTRODUCTION

The geomagnetic method of geophysical survey is widely used for mineral and oil exploration. It is effective in detecting magnetic minerals and investigating the basement features such as lineaments (faults, fractures, dyke etc), intrabasement and suprabasement block. This method make use of magnetic properties of rocks.

The aeromagnetic survey has been applied in mapping the magnetic anomalies in the earth's magnetic field and correlated with the underground geological structure [1]. The main purpose of the magnetic survey is to detect minerals or rocks that have unusual magnetic properties which reveal themselves by causing anomalies in the intensity of the earth's magnetic field [2]. There would always be a magnetic susceptibility contrast across a fracture zone due to oxidation of magnetite to hematite and/or infilling of fracture planes by dyke-like bodies whose magnetic susceptibilities are different from those of their host rocks [3]. Such geological features may appear as thin elliptical closures or nosings on an aeromagnetic map. Faults usually show up by abrupt changes or close spacing in orientation of the contours as revealed by the magnetic anomalies.

In magnetic survey total field are usually measured. Modern high-resolution magnetometers are able to collect data with an accuracy of 0.001 nT [4].

Removal of the regional from total field anomaly result into residual anomaly compose of positive and negative magnetic anomalies. A positive magnetic anomaly is a reading of magnetic field strength that is higher than the regional average which can indicate hidden ore and geologic structures, while a negative magnetic anomaly is a reading of magnetic field strength that is lower than the regional average [5].

The most magnetic mineral usually responsible for the magnetic properties of rock is the magnetite content which has Curie temperature of 578℃. It is responsible for the magnetic susceptibility of rock and hence basement rock is much more magnetic than the sedimentary rock [6] and in the geophysical literature there are number of Tables of magnetic susceptibility of rocks [7-10]. Again, among the basement rock, basic igneous rock are usually more magnetic due to their relatively high magnetite and mafic content.

The magnetic body consists of magnetic particles or dipoles, which is a vector quantity with an associated sense of direction. Since the orientation of the dipoles, which determine the magnetization may be in any direction, definition of the magnetic state or magnetization of a body requires both magnitude and direction. The magnetic properties of rock may vary over a wide limit. This variation may be considered as a result of the variation in the volume density of the elementary magnets, the ease with which they can be oriented, and the persistent with which they maintain a given orientation once it has been acquired [6].

All rocks contain some magnetite from very small fractions of a percent up to several percent, and even several tens of percent in the case of magnetic iron ore deposits. The distribution of magnetite or certain characteristics of its magnetic properties may be utilized in exploration or mapped for other purposes. Iron objects in the earth's magnetic field, whether something buried or intentionally planted for subsequent retrieval, would also create a detectable magnetic anomaly. Cultural features associated with man's habitation can frequently be detected through magnetic surveys owing to the contrast in magnetite associated with numerous artificial features such as man-made structures, voids, or the enhanced magnetic effects of baked clays and pottery [11].

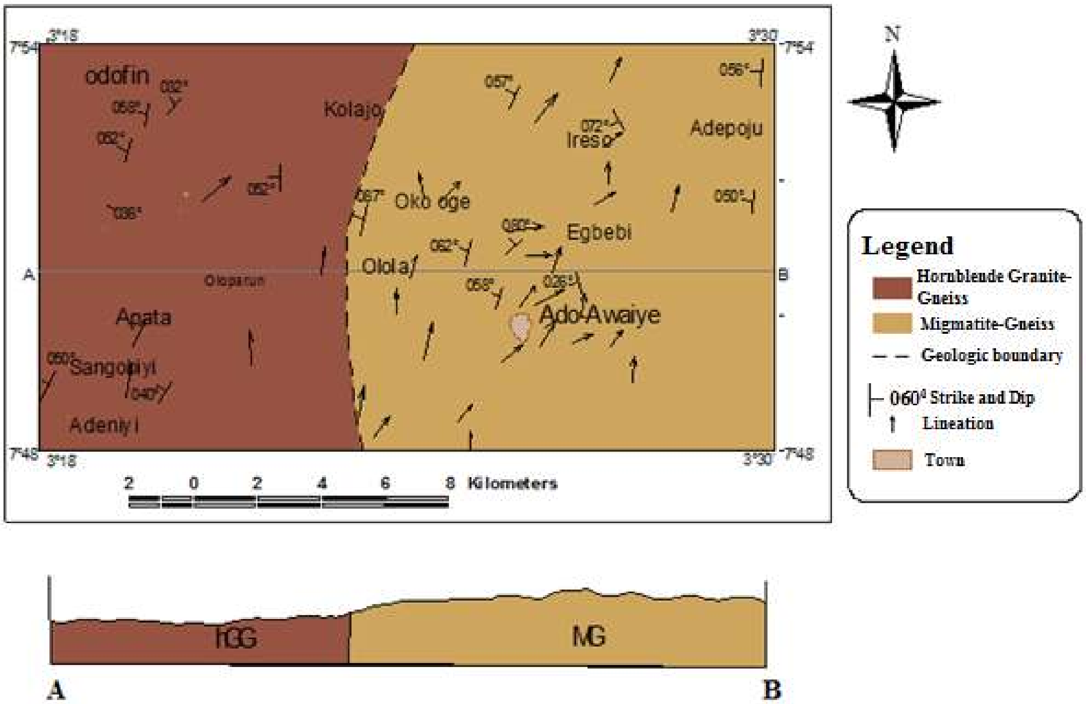


Fig. 1. Geological map and cross-section Around Iseyin Area (Ado-Awaiye) and its environs Southwestern Nigeria [12]

This paper titled ‘Geomagnetic Signature and Depth Estimate of Basement Rock is aimed at revealing the character of different basement rocks as determined from variability in magnetic signature and consequently the depth to the anomalous body causing the magnetic variation across the study area. The work is first of its kind as previous work are usually geological mapping on a regional scale and do not reveal the local variation in magnetic field which is a consequence of lithologic heterogeneity in the subsurface and hence the need for this detailed ground magnetic campaign.

Again this paper has been able to utilise two different half-width methods to estimate depth at a location, compare the methods and thereby suggest drilling in order to verify the best suited method and this is an advancement to previous work been carried out by past workers.

1.1 Location and Geology of the Study Area

The study area is part of Ado-Awaiye and its environs which falls within Latitudes 07°48’00’’N and 07°54’00’’N and Longitudes 003°18 ’00’’E and 003°30 ’00’’E.

The area is underlain by two major rock unit; the migmatite-gneiss and the hornblende granite-gneiss including minor rock unit; amphibolite and pegmatite [12] as shown in the Fig. 1.

2. MATERIALS AND METHODS

G856AX Mag ™ proton-precision magnetometer was the main equipment used for this exploration exercise and the fundamental principles upon which the proton precision magnetometer works was disclosed by [13]. Other materials used in the study include Global Positioning System (GPS), measuring tape, peg and cutlass.

The geomagnetic survey covers area of about 170 m by 90 m. The survey run in almost east - west direction. Nine magnetic profile lines were designed with each having an average length of 170 m. Station interval of 10 m was used and inter-profile interval of 10 m was also adopted and hence a grid coverage of 10 m by 10 m was maintained throughout the magnetic survey. Each station was occupied and the total magnetic field intensity was taken manually and at the same time saved electronically in the magnetometer for later onward computing. As a precaution, magnetic cleanliness was undertaken, that is, man-made magnetic material was avoided since it constitutes noise in the survey.

Total field intensity in nanotesla were measured and recorded at each station and it was subjected to computer processing. Magnetic map were produced and profiles drawn. The residual fields were obtained for each profile line by fitting line of best fit into the total regional field and this was achieved by subtracting the line of best fit from the regional at each station.

After necessary data processing, the result was presented in form of magnetic map and profiles.

3. RESULTS AND DISCUSSION

3.1 Data Presentation and Analysis

Magnetic readings in nanotesla were recorded in the field. It was later processed using computer software to present the three-dimensional (3-D) view (Fig. 2). Total magnetic intensity contour map (Fig. 3), and residual magnetic map with all the traverse lines (Fig. 4) were also produced for interpretation purpose.

3.2 Interpretation

The interpretation of the magnetic data is done in two steps. They include:

- Qualitative Interpretation
- Quantitative Interpretation.

3.2.1 Qualitative Interpretation

This interpretation is based on visual inspection of the magnetic contour map. The magnetic contour is widely spaced at the northern part of the map indicating that the depth to magnetic basement is relatively high. But at the southern part of the map the magnetic contours are closely spaced indicating a shallow magnetic basement (Figs. 3 and 4). This interpretation was confirmed in the field by the presence of two relatively low lying outcrop which serve as a control. Measurements were taken close and across the outcrops.

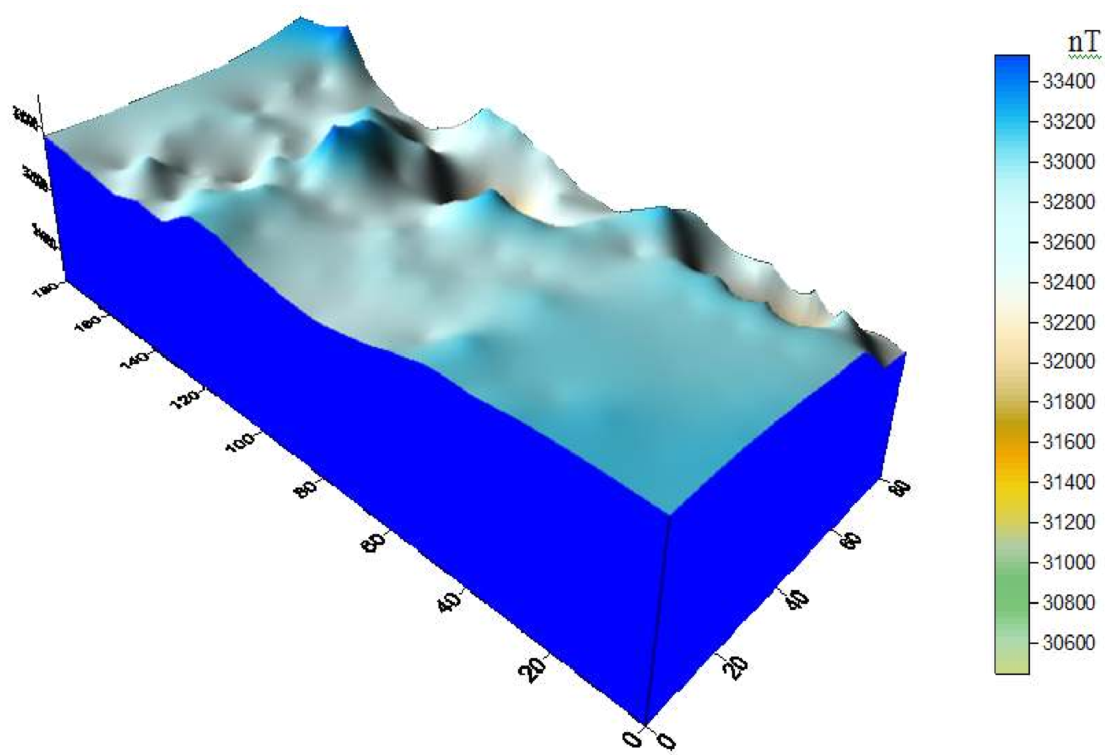


Fig. 2. Geomagnetic data presented in three dimensional view (3-D) of the study area

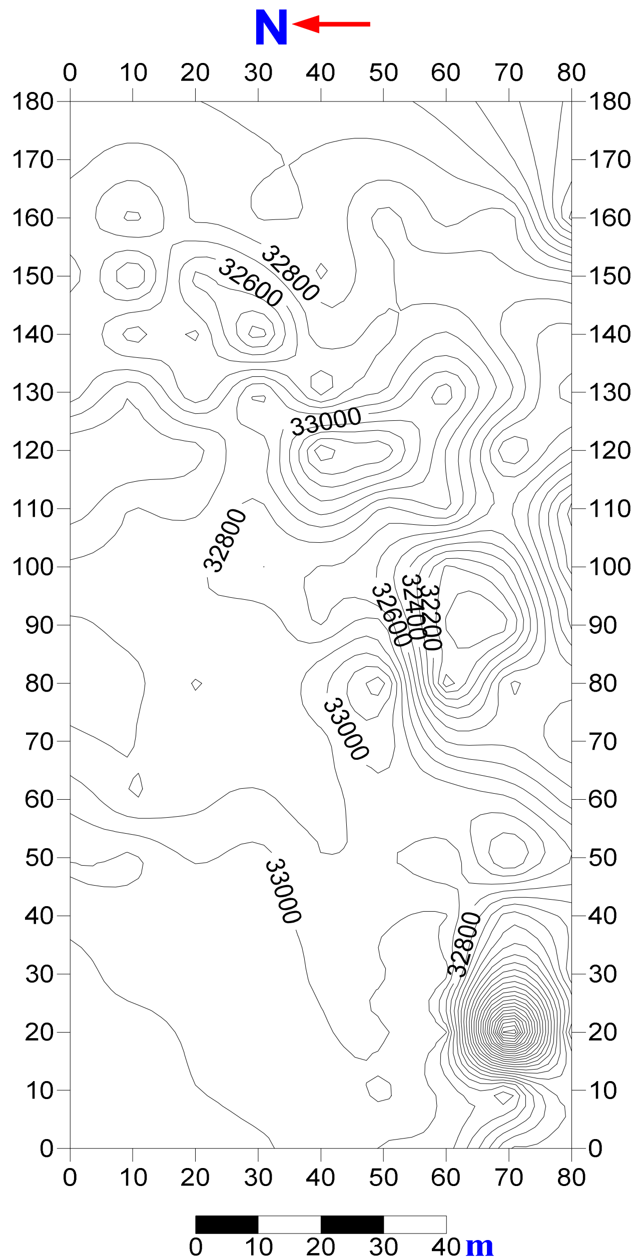


Fig. 3. Total magnetic field intensity contour map of the study area (part of Iseyin, Ado-Awaiye)

The variation in total magnetic field intensity from 30446.47 nT to 33536.10 nT is a function of variation in lithology of the basement with the highest value corresponding to mafic material probably amphibolite schist and the intermediate to low magnetic intensity which may correspond to granitic component of the migmatite-gneiss of the magnetic basement. Therefore basement rocks at the western part of the map show higher magnetic character and signature than those of the east.

The inward increase in magnetic contour may indicate a suprabasement block with conical geometry and this occur from central to eastern part of the map while those with magnetic contours that increases outward (intrabasement block) may be termed as a basement depression filled by materials of low magnetic susceptibility (mainly weathered material such as clay, clayey sand and sandy horizons).

Also, the residual field intensity is characterized by both negative and positive anomaly with negative anomaly indicating weathered material filling the basement depression.

The presence of elliptical closure and nosing in contours which are closely spaced, linear and sub-parallel in the total magnetic intensity and residual map represent geologic lineament such as fault, dyke or local fractured zones passing through the area and this occurs at the center to right hand side of the magnetic map. Such magnetic susceptibility contrast across a fracture zone may be probably due to oxidation of magnetite to hematite or infilling of fracture zone by dyke-like bodies (such as amphibolite) whose magnetic susceptibilities differ from those of their host rocks.

Finally, the intrabasement block can serve as water collecting center while basement fracture can serve as pathway for groundwater and hence can be exploited for groundwater development.

3.2.2 Quantitative interpretation

The depth estimate constitutes the quantitative interpretation of magnetic data. The interpretation of geophysical anomalies is often based on the analysis of data observed along selected profiles. The main objective of analyzing data is to remove unwanted signals from the recorded data leaving ideally only data having geological meaning.

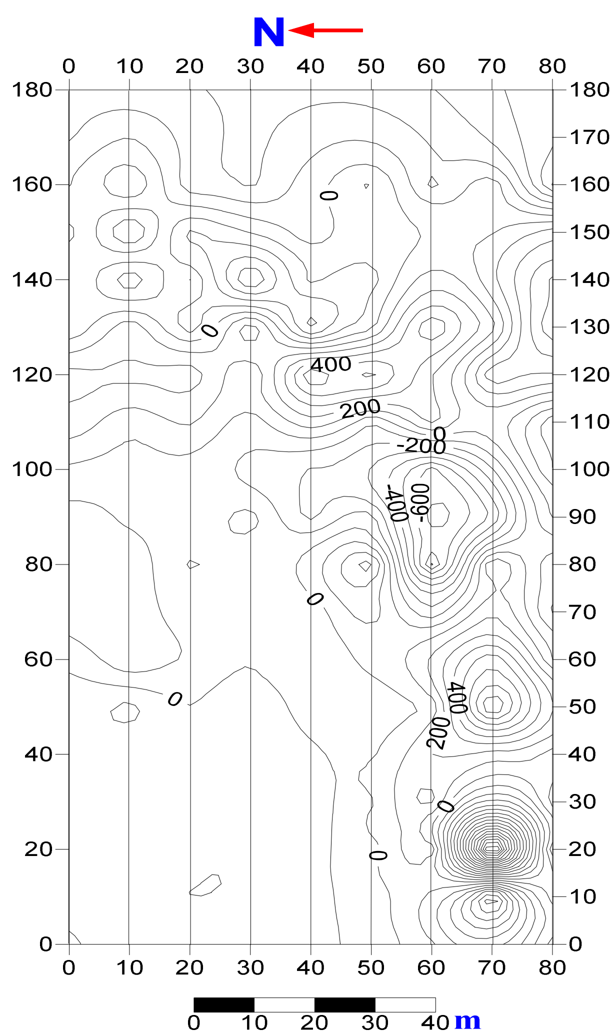


Fig. 4. Residual magnetic field intensity map of the study area with traverse lines (part of Iseyin, Ado Awaiye)

3.2.3 Anomaly depth estimation

Much is written on the variety and relative merit of methods for estimating the depth to the source of anomalies. Since the magnetometer is primarily a tool for subsurface mapping and detection, it follows that determination of the depth as well as edges of bodies is important in its application to geological exploration and search. Also, knowledge of the depth of a particular formation or source may have considerable geological significance as it determines the nature or configuration of a formation, the slope of its surface and its discontinuities.

3.2.4 Half-width method

Half-width method is the most common method of depth estimation. It makes use of the shape of the anomaly. The basis for depth determination is that variation in depth affects the shape of an anomaly. That is, the shallower the depth of an anomalous body, the narrower and sharper the anomaly shape and the deeper the magnetic source, the broader the anomaly and it tends to flatten out (Fig. 5).

For simple forms of anomaly sources, the depth to their centers is related to the half-width of the anomaly. Half-width can be defined in either of the two ways and hence provide method (a) or method (b) for calculating the depth to the anomalous body buried beneath the subsurface as shown in Fig. 6.

(a) The half-width is the half horizontal distance between the principal maximum (or minimum) of the anomaly (assumed to be over the center of the source) and the point where the value is exactly half the maximum anomaly or (b) Half the width between points where the anomaly is one-quarter and three-quarters of the maximum anomaly amplitude.

This rule is valid for various simple shaped forms including gently sloping surfaces such as topography on basement bedrock or dip-slip fault in horizontal strata which are assumed and modeled by an infinite slab.

For an infinite slab, the half-width $X_{1/2}$ equals depth to the basement Z.

The depth to various points on the surface of crystalline rock or magnetic basement allows one to map the surface and its topography and structures of various depths and to infer thickness of overburden materials or conformable magnetic basement structures above it for exploration of ores, placer deposits or groundwater.

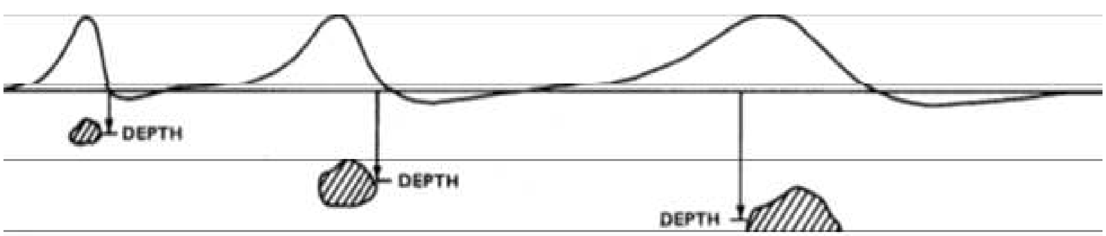


Fig. 5. Effect of depth on anomaly shape and amplitude

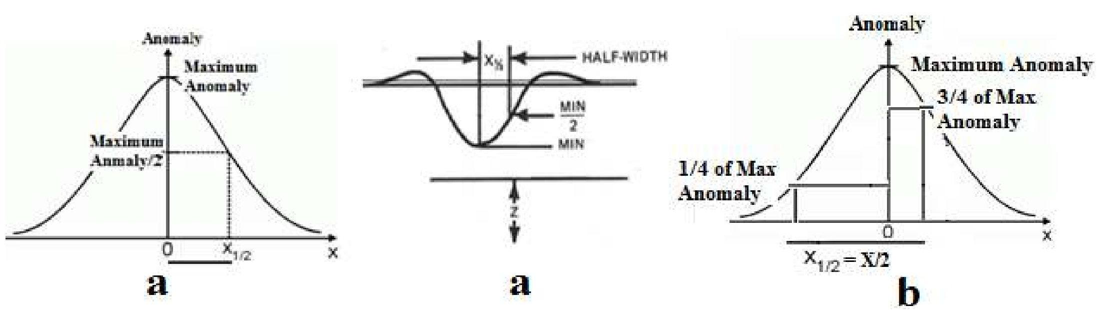
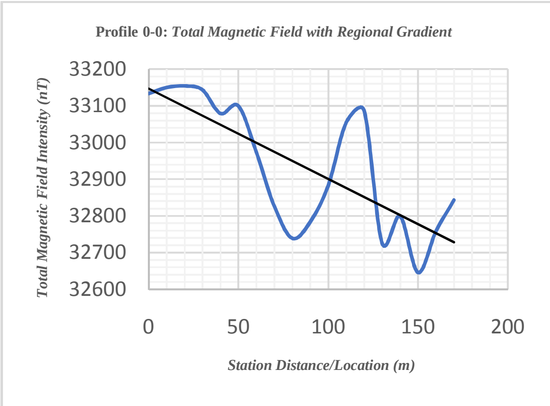
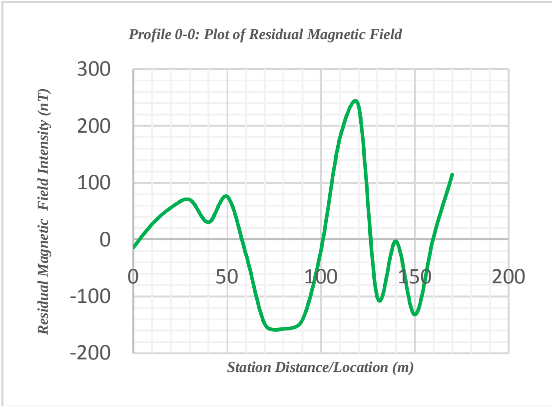


Fig. 6. The two methods of calculating half-width from anomaly shape for depth estimate

Below are the profiles taken mainly from west to east along each traverse line for detail qualitative interpretation.


Profile 0-0: Total Magnetic Field with Regional Gradient
Total Magnetic Field Intensity (nT)
33200
33100
33000
32900
32800
32700
32600
0
50
100
150
200
Station Distance/Location (m)


Profile 0-0: Plot of Residual Magnetic Field
Residual Magnetic Field Intensity (nT)
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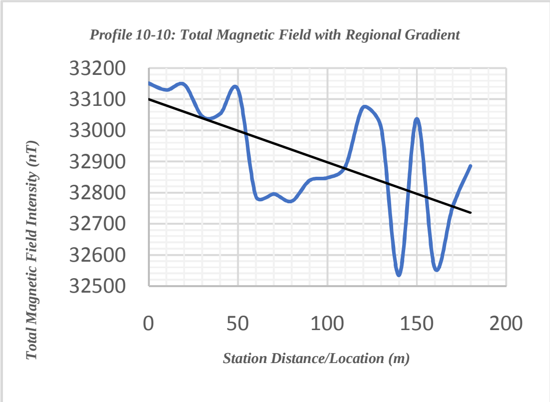
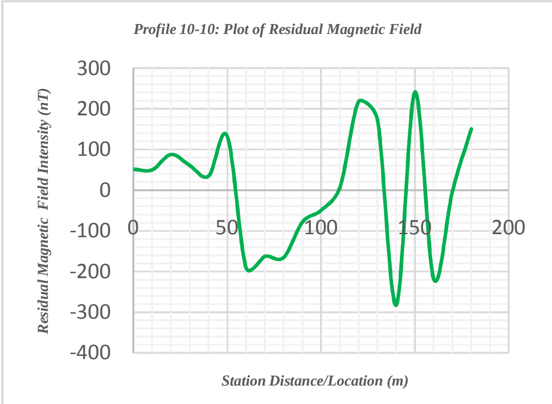
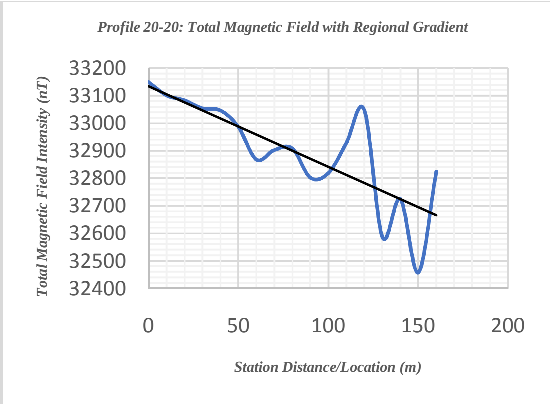
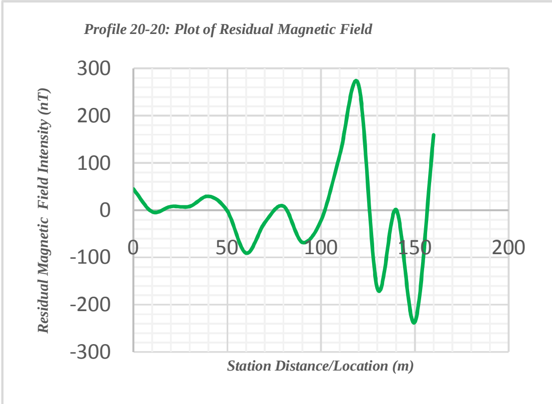
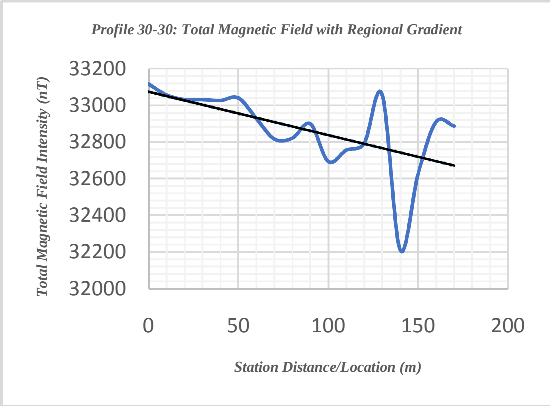
200
100
0
-100
-200
0
50
100
150
200
Station Distance/Location (m)

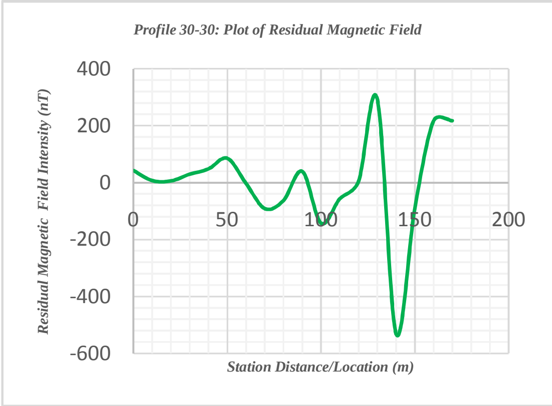

Profile 10-10: Total Magnetic Field with Regional Gradient
Total Magnetic Field Intensity (nT)
33200
33100
33000
32900
32800
32700
32600
32500
0
50
100
150
200
Station Distance/Location (m)

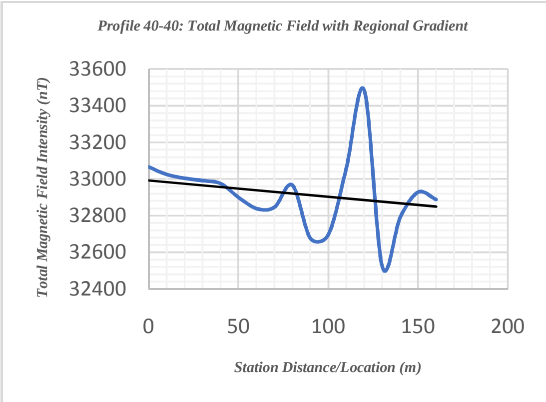

Profile 10-10: Plot of Residual Magnetic Field
Residual Magnetic Field Intensity (nT)
300
200
100
0
-100
-200
-300
-400
0
50
100
150
200
Station Distance/Location (m)

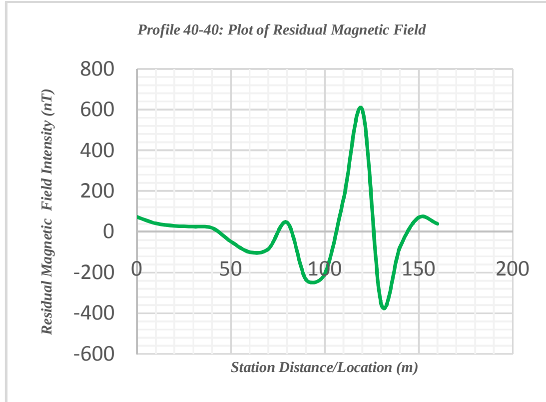

Profile 20-20: Total Magnetic Field with Regional Gradient
Total Magnetic Field Intensity (nT)
33200
33100
33000
32900
32800
32700
32600
32500
32400
0
50
100
150
200
Station Distance/Location (m)

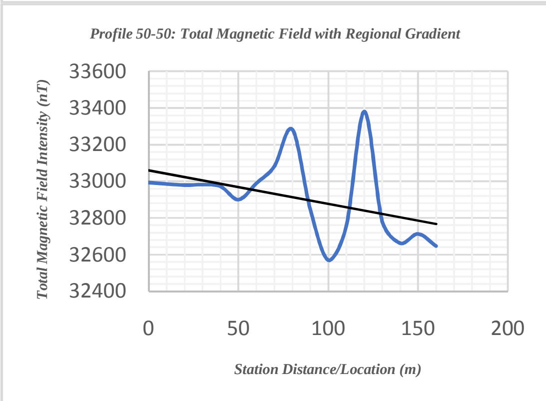

Profile 20-20: Plot of Residual Magnetic Field
Residual Magnetic Field Intensity (nT)
300
200
100
0
-100
-200
-300
0
50
100
150
200
Station Distance/Location (m)

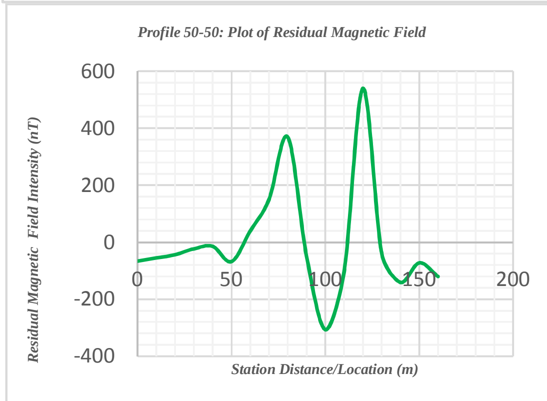

Profile 30-30: Total Magnetic Field with Regional Gradient
Total Magnetic Field Intensity (nT)
33200
33000
32800
32600
32400
32200
32000
0
50
100
150
200
Station Distance/Location (m)

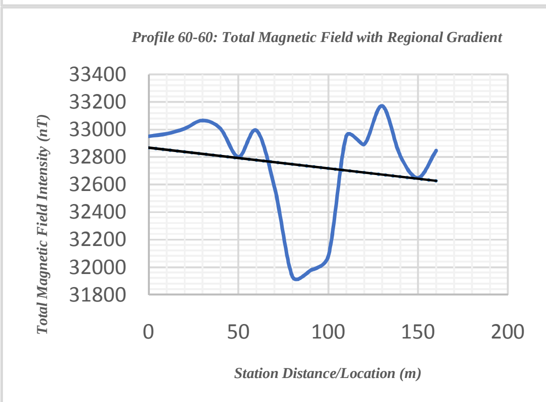

Profile 30-30: Plot of Residual Magnetic Field
Residual Magnetic Field Intensity (nT)
400
200
0
-200
-400
-600
0
50
100
150
200
Station Distance/Location (m)

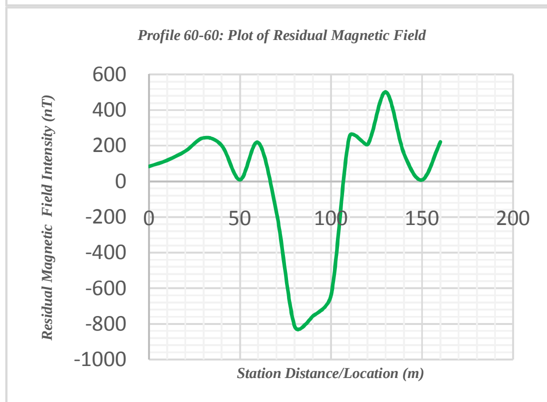

Profile 40-40: Total Magnetic Field with Regional Gradient
Total Magnetic Field Intensity (nT)
33600
33400
33200
33000
32800
32600
32400
0
50
100
150
200
Station Distance/Location (m)

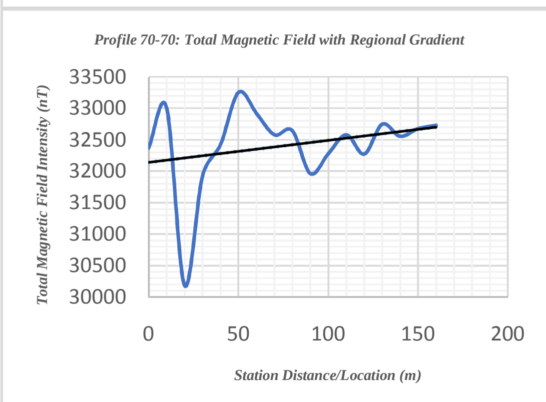

Profile 40-40: Plot of Residual Magnetic Field
Residual Magnetic Field Intensity (nT)
800
600
400
200
0
-200
-400
-600
0
50
100
150
200
Station Distance/Location (m)

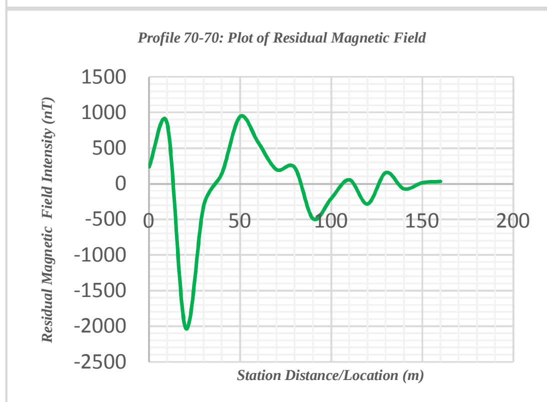

Profile 50-50: Total Magnetic Field with Regional Gradient
Total Magnetic Field Intensity (nT)
33600
33400
33200
33000
32800
32600
32400
0
50
100
150
200
Station Distance/Location (m)

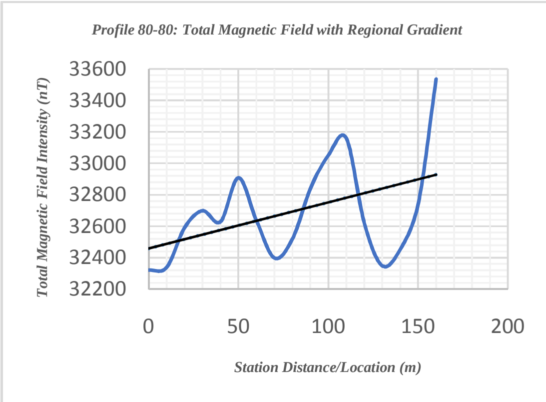

Profile 50-50: Plot of Residual Magnetic Field
Residual Magnetic Field Intensity (nT)
600
400
200
0
-200
-400
0
50
100
150
200
Station Distance/Location (m)

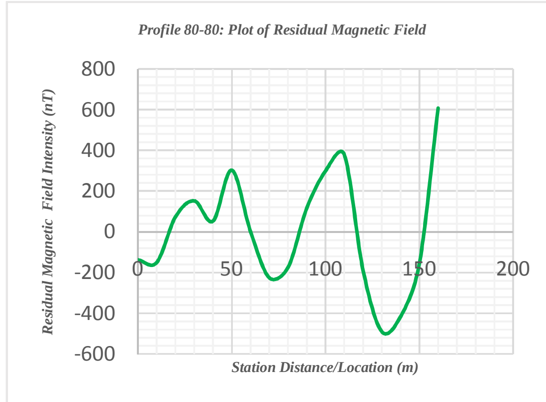

Profile 60-60: Total Magnetic Field with Regional Gradient
Total Magnetic Field Intensity (nT)
33400
33200
33000
32800
32600
32400
32200
32000
31800
0
50
100
150
200
Station Distance/Location (m)


Profile 60-60: Plot of Residual Magnetic Field
Residual Magnetic Field Intensity (nT)
600
400
200
0
-200
-400
-600
-800
-1000
0
50
100
150
200
Station Distance/Location (m)


Profile 70-70: Total Magnetic Field with Regional Gradient
Total Magnetic Field Intensity (nT)
33500
33000
32500
32000
31500
31000
30500
30000
0
50
100
150
200
Station Distance/Location (m)


Profile 70-70: Plot of Residual Magnetic Field
Residual Magnetic Field Intensity (nT)
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
0
50
100
150
200
Station Distance/Location (m)





Each of the profile was subjected to regional – residual anomaly separation by fitting a regional gradient surface to the total field (left) to produce the residual field (right) after necessary subtraction. This was followed by half-width calculation which the result is summarised and presented in Table 1.

It is observed that the depth determined from both methods a and b are in some instances the same while they differ in other instances. This depends on or related to shape of the anomaly. They are the same when the anomaly is symmetrical over the causative body and differ from each other when the anomaly shape lies assymmetrically over the anomalous body. Therefore, the most suitable and appropriate method for basement depth estimate between method a and b can only be confirmed by drilling result. This will prevent erroneous depth calculation as fractions of kilometer(s) are great depth in meter especially when it is a question of estimation of sedimentary cover in aeromagnetic campaign for oil exploration.

Three profiles have been selected for detailed analysis and explanation. These serve as representatives of the others.

3.2.5 Profile 0 – 0

From the anomaly width of the residual field, the depth to magnetic basement along this profile varies. Between 4 m to 58 m ground distance, the magnetic basement depth is approximately 20.5 m to 22.0 m, between 58 m to 102 m, it is approximately 16 m, between 102 m to 127 m, it is approximately 8.5 m to 9.0 m, between 127 m to 140 m it is approximately 3.5 m and between 140 m to 160 m, it is 5.0 m. Therefore the minimum depth is 3.5 m and maximum depth is 22.0 m with an average of approximately 12.1 m. The anomaly amplitude also ranges from -157.0 nT to 235.1 nT.

3.2.6 Profile 30 – 30

The basement depth along this traverse line varies extensively. Between 20 m to 60 m, the depth estimate from the anomaly width is 7 m to 11.5 m, between 60 m to 85 m, it is 7.5 m to 8.0m, between 85 m to 93 m is about 2.5 m, between 93 m to 120 m, it is 6.0 m to 6.5 m, between 120 m to 134 m, it is 4.0 m and finally between 134 m to 152 m, it is 4.5 m to 5.0 m. Minimum and maximum depth is 2.5 m and 11.5 m respectively with an average of approximately 6.3 m. Also minimum anomaly amplitude of -530.7 nT and maximum value of 292.7 nT characterize this profile.

3.2.7 Profile 70 – 70

Along this profile line, the depth to magnetic basement is 4.5 m to 5.5 m between 0 m to 13 m ground distance, it is 4.5 m to 5.0m between 13 m to 36 m, it is 7.5 m to 9.0 m between distance of 36 m to 84 m, it is 5.0 m to 6.3 m between 84 m to 106 m, it is 3.8 m to 4.9 m between 112 m to 126 m and it is 3.0 m to 3.5 m between 126 m to 137 m. Therefore, the minimum depth is 3.0 m and maximum depth to basement is 9.0 m with a mean depth of about 5.2 m. In addition to depth variation, this profile is also characterized by minimum anomaly of -2022.5 nT and peak value of 940.1 nT.

Table 1. Basement depth estimated from haf-width using both method a and b.

Profile	Ground distance (m)	Depth to basement (m)		Anomaly type & value (nt)
		a	b	
0 - 0	4 to 58	20.5	22.0	+75.5
	58 to 102	16.0	16.0	-157.0
	102 to 127	8.5	9.0	+235.1
	127 to 140	3.5	3.5	-101.0
	140 to 160	5.0	5.0	-132.1
10 - 10	0 to 40	7.5	7.5	+87.7
	40 to 53	4.5	4.3	+132.2
	54 to 110	15.5	13.5	-190.6
	110 to 134	9.0	9.0	+195.7
	134 to 146	3.5	3.5	-282.5
	146 to 156	3.5	3.5	+241.1
	156 to 170	5.0	4.0	-281.1
20 - 20	28 to 50	6.5	6.5	+29.9
	50 to 75	6.0	6.0	-90.5
	82 to 102	6.0	6.0	-67.6
	102 to 126	6.0	7.0	+265.4
	126 to 140	3.5	3.5	-165.3
	140 to 156	5.5	5.0	236.2
30 -30	20 to 60	7.0	11.5	+85.2
	60 to 85	8.0	7.5	-91.5
	85 to 93	2.5	2.5	+39.1
	93 to 120	6.0	6.5	-142.9
	120 to 134	4.0	4.0	+292.7
	134 to 152	5.0	4.5	-530.7
40 - 40	44 to 75	10.0	12.0	-100.0
	83 to 106	9.0	8.5	-206.9
	106 to 126	5.5	6.0	+599.0
	126 to 144	4.5	4.0	-353.3
50 – 50	40 to 57	5.0	5.0	-67.8
	57 to 89	6.5	8.5	+368.7
	89 to 111	7.5	7.5	-306.6
	111 to 129	5.0	5.0	+539.9
	129 to 148	4.0	5.0	-141.0
60 – 60	0 to 45	11.5	13.0	+244.4
	50 to 67	4.5	4.5	216.8
	67 to 107	14.0	16.5	-815.0
	107 to 152	13.0	13.5	+501.3
70 – 70	0 to 13	4.5	5.5	+837.1
	13 to 36	5.0	4.5	-2022.5
	36 to 84	9.0	7.5	+940.1
	84 to 106	6.3	5.0	-491.9
	112 to 126	3.8	4.0	-286.6
	126 to 137	3.5	3.0	+153.9
80 – 80	16 to 40	7.5	7.3	+151.9
	40 to 60	5.5	5.5	+302.9
	60 to 86	9.0	8.5	-226.3
	86 to 117	10.0	11.0	378.5
	117 to 152	12.5	12.0	-491.3

4. CONCLUSION AND RECOMMENDATION

From the geomagnetic study, the area is underlain by magnetic basement with the total field ranging from 30446.50 nanotesla to 33536.10 nanotesla. The magnetic basement constitute migmatite-gneiss with associated amphibolite which is rich in opaque mineral such as magnetite. This most certainly responsible for the relative high magnetic readings observed at some parts. The magnetic basement is relatively shallow close to the extreme right side of the map where an outcrop is encountered and relatively deep on the left side of the map. The overburden thickness ranges from 2.5 m to 22.0 m and hence the basement topography is relatively non uniform.

Few basement structures such as fracture, intrabasement and suprabasement blocks were inferred from the magnetic map. The area is not mineralized as it has already being ascertained from the geological mapping of the area. Drilling may be carried out to confirm the interpretation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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