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Magnetic rocks distribution and depth to basement analysis on an old quarry site, Abeokuta, SW Nigeria

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Abstract

Geomagnetic study was carried out to investigate the distribution and depth of formations of different magnetic rocks on an old quarry site, Abeokuta, Southwestern, Nigeria. Eight ground magnetic profiles were established with 10 m spacing intervals orientated in West-East and North-South directions, and ranged between 110 and 190 m. A total of 223 data sets were acquired and corrected for all forms of magnetic variations. The resulting residual anomalies were plotted against distance using Microsoft Excel tool. Also, these anomalies were modeled into 2D and 3D contour sections using Surfer 10. The depth to basement analysis was carried out using Peter's half slope graphical method. The resulting profiles and contour sections revealed variable anomalies which indicated contrast in the magnetic distributions of the subsurface. Mineral rocks with average (0-150 nT) magnetic susceptibilities dominated the profiles, and this indicated that the study area is on pegmatite or Quartz vein which probably harbored Beryl, Graphite, Sandstone, Quartz, Tantalite and Mica in both massive and disseminated quantities. Regions with high (150-300 nT) and low (0 to -150 nT) magnetic susceptibilities were also observed across the profiles. Mineral rocks with very thin bodies were observed at depths 3.48-17.42 m, intermediate bodies were buried at depths 2.61-13.06 m, while very thick bodies were located at depths between 2.09 and 10.45 m. The depth of the magnetic sources revealed that the major and minor mineral rock contact in the study area.

Keywords: *Geomagnetic, Susceptibility, Distribution, Mineral Rocks, Depth*

1. Introduction

Geomagnetic technique generally involves the measurement of magnetic anomalies in the subsurface as the earth's magnetic field intensities or vertical gradients of the earth's magnetic field. These anomalies are caused by the induction of magnetic rocks in the subsurface as a result of secondary magnetization induced in a ferrous body by the earth's magnetic field. The response of the induced anomaly depends on the geometry, orientation, size, depth and magnetic susceptibility of the ore body as well as the inclination and intensity of the subsurface earth's magnetic field (Mariita 2007; Meri-Liisa 2015; Cyril and Adedibu 2016; Biswas 2016). Magnetic method revealed the coherent pictures of the magnetization distributions of the earth crust and is not disturbed by soil, waterways and lakes that may cover the bedrock (Meri-Liisa 2015). According to Roger (2008), induced magnetic anomalies generally exhibits asymmetrical, south up or north down signatures, positive response to the south and negative response to the north of the object. Ground magnetic method is very effective in delineation of both thin and large metallic ores (Kayode et al. 2013; Ojo et al. 2014), it responses to small changes in magnetic variations in the subsurface. A thin body can be detected to a depth of about 4 meters (Ojo et al. 2014), while larger metallic objects can often be located to greater depths. The appraisal of the depths of buried objects from the magnetic data has drawn attention in mineral rock explorations (Ojo et al. 2014; Mandal et al. 2015; Biswas 2016). Magnetic prospecting, the oldest form of geophysical exploration is used to explore for both oil and mineral rocks (Telford et al. 1990). Geophysicists use the measurements of earth's magnetic field intensities to reveal the subsurface magnetic susceptibility variations. The data obtained gives the sum of the earth's magnetic and induced magnetic body fields. The larger the magnetic body in size and quantity, the stronger the induced fields. If the data can be filtered in such a way that the natural fields can be removed, the results revealed varied regions of magnetic susceptibilities. Magnetic surveys are done from all conceivable platforms such as ground, vehicle, air, marine, satellite and in boreholes, and the results obtained are usually presented as profiles, maps and pseudo-sections. Raw data may be interpreted directly, significant processing may be applied, and inversion to estimate models of subsurface susceptibility distribution can also be carried out (Umego and Ojo 1995; Reynolds 1997; Ojo and Popoola 2014). The application of magnetic method is so wide that it has become a culture to include magnetic survey in every comprehensive or integrated geophysical investigation (Folami 1980; Nwosu et al. 2015). Mineral deposits, an anomalous of metaliferous minerals, contain mineral rocks with varied physical properties. Magnetite, Pyrite or pyrrhotites are

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common minerals in ore deposits with distinctive physical properties which greatly affect the geophysical responses. The geophysical expressions of mineralized systems or ore deposits are influenced by petro-physical properties, environmental conditions and geological or geometrical factors (Meri-Liisa 2015). Magnetic susceptibility is probably the most easily measurable petro-physical parameter. The magnetic susceptibility of rocks is in principle controlled by the type and amount of magnetic minerals contained in the rocks (Frantisek et al, 2009). Ground magnetic data of an old quarry site is analyzed with the objective of delineating its concealed mineral rocks, as well as mapping the lithologic signatures, depth to magnetic sources and basement structures. This research is of high importance due to the recent advances in science and engineering which had led to increase in the demand of mineral deposits used in making electronic components, surgical implants, heat conductors, sutures, sculptures, bricks and so on. The increase in global demand of these mineral rocks had led to the renewed interest in the search for economically viable mineral deposits in Nigeria (Okunlola 2005; Okunlola and Jimba 2006; Okunlola and Ofonime 2006; Ojo 2013; Ojo et al. 2014; Nwosu et al. 2015).

2. The study area and its geological setting

The study area is located in Saje community, Abeokuta South Local Government Area of Ogun State, Southwestern Nigeria and covers an approximated area of 119,000 m^2. It is within an old quarry site abandoned by Aggregate Granite Industries (AGI) since 1999, and lies within latitude N07^{0}11.201'-N07^{0}11.480' and longitude E003^{0}21.001'-N003^{0}22.250'. Abeokuta is located on basement complex of igneous and metamorphic origin which overlain various sedimentary rocks (Fig 1).

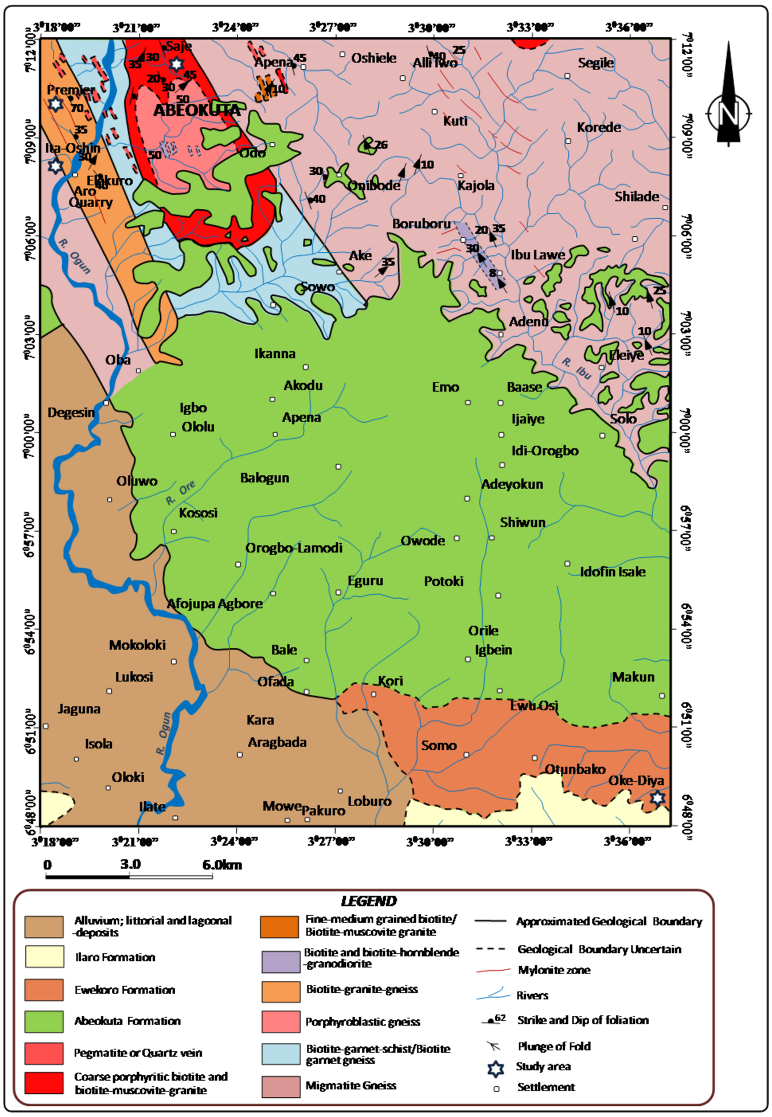

Fig 1. Geological map of Abeokuta showing the study area

The rugged rock-strewn relief is prominent towards the north, in the central and south-eastern parts of the city. The basement rocks comprised of folded schist, quartzite, gneiss, older granite and amphibolites or mica schist (Jones and Hockey 1964; Rahaman 1976). The oldest Formation identified in Dahomey basin is the Abeokuta Formation (Jones and Hockey 1964), this was upgraded to a group status with three Formations by Omatsola and Adegoke (1981). Ise Formation has a conglomeratic and gritty base overlain by coarse to medium grained sandstone with inter-bedded kaolinite. Ise Formation is followed by a coarse to medium grained sandstone with inter-bedded shale, siltstone and clay stone, having a sandy fancies that is tar-bearing while the shale is organic-rich. The youngest is Araromi Formation, which is Cretaceous and made up of fine to medium grained sandstone at the base, overlain by shale and silt stone with inter-bedded limestone, marl and lignite. Abeokuta group is overlain by Ewekoro Formation, made of a limestone unit reported to be highly fossiliferous (Oyawoye 1964; Kogbe 1989).

3. Methodology

Ground magnetic study was used for detailed mapping in order to understand both the magnetic susceptibility distribution and mineral rock to basement (depths) analysis based on qualitative data interpretations. The field techniques involved the measurements of magnetic component amplitudes at discrete points along eight profiles. The geomagnetic survey was carried out using a proton precession magnetometer (model G-856AX) aligned across the study area as shown in Fig 2. The length of each profile depends on the proximity of the study area to the neighboring community, and ranged between 110 and 190 m.

A station interval of 5 m was adopted, and at each station, the total magnetic intensities were measured and the geo-coordinates were also recorded using Global Positioning System. A based station was set up about 800 meters away from the study area, and the ground magnetic readings were recorded at every thirty minutes interval; this is to correct the raw survey data for the diurnal variation effects.

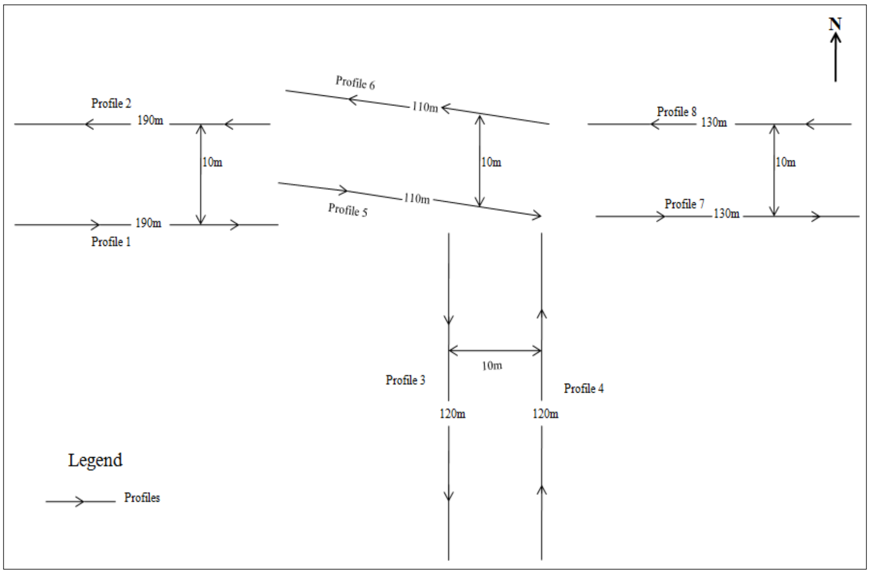

Fig 2. Survey layout

This correction is required since the profile lines were relatively long (above 100 m), and the objective of the survey is to have a high quality magnetic contour map, which is a truly expressive of deep-seated anomaly sources. The base stations readings were thoroughly checked to remove any effects due to artificial materials. A total of 223 data sets were obtained and also inspected for spikes, gaps, instrument noise and International Geomagnetic Reference Field (IGRF) corrections. The ground magnetic survey was carried out on a relatively small spatial extent area, then, coordinates N07^{0}11.050' and E003^{0}23.067' were used as the base coordinates for IGRF and other field calculations, and the elevation was taken as 0 m. The geomagnetic field parameters were calculated as: declination (3.8078°), inclination (12.6831°), horizontal intensity (31609.2 nT), north component (31539.4 nT), east component (-2099.1 nT), vertical component (-7113.7 nT), and total field (32399.8 nT). The resulting residual anomalies were plotted against distance using Microsoft Excel tool, and 2D as well as 3D surface distributions of the residual anomalies were also generated using Surfer 10.

In order to deduce the depths of the magnetic bodies in the subsurface, Peter's half slope method was adopted (Peters 1949; Ojo et al. 2014; Adegoke and Layade 2014). This method is a theoretically based graphical method (Fig 3) which is based on the mathematical expression for magnetic anomalies with vertical polarization over vertical dikes. Depending on the size of the magnetic object, the mineral body is assigned with an index value ranging from 1.2-2.0. The product of an index value with the depth of magnetic source (h) is approximately equal to the lateral distance (half maximum slope distance, d), that is, the lateral distance is divided by the index value to obtain the depth of the metallic body. For bodies having very thin depth-to-width ratios, d=1.2h, and for bodies having very thick depth-to-width ratios, d=2.0h. For an average depth-to-width ratios, d=1.6h. The depth is determined in meters. If the object's size is not ascertained, the distance is divided by both 1.2 and 2.0 to determine the depth of the object.

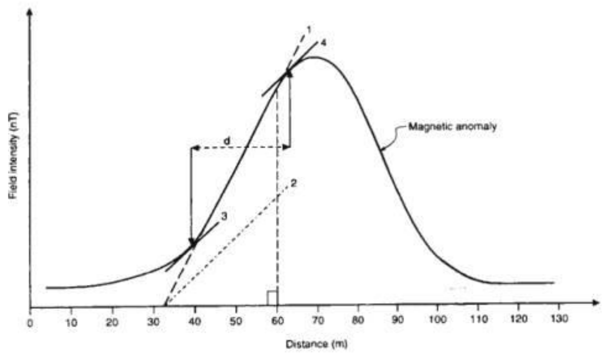

Fig 3. Peter's half slope method for depth-to-basement analysis (Peters 1949)

4. Results and Discussion

Magnetic residual anomalies can be presented in several ways (Kayode and Adelusi 2010; Ojo et al. 2014; Biswas 2016). In this study, profiling and contour mapping were adopted to make geological deductions. Information on the subsurface geological structures, lithology and trend can be obtained from the range of magnetic intensities obtained (Nabighian et al. 2005).

4.1. Profiling

This is an old form of presenting magnetic data. The magnetic profiles were generated using Microsoft excel, and the method showed the magnetic responses (susceptibilities) in graphical forms (Figs 4a-d). These profiles were also used to estimate the depth to magnetic sources in the study area using Peters' half slope technique. Profiles have an advantage of being able to show details that cannot be revealed in the grid-based presentations, such as, contour mapping (Ojo et al. 2014).

Profiles 1 and 2 (Fig 4a) revealed magnetic intensities ranging from -120 to 220 nT to a profile length of 190 m. Profile 1 indicated high magnetic response of about 180 nT at profile distances 20-40 m, and low magnetic response of 0 nT at profile distances 20, 60-70 and 120-140 m. Profile 2 revealed high magnetic intensities of about 150 and 220 nT at profile distances 10-20 and 20-30 m respectively. Low magnetic intensities of about -100 (20-30 and 130-140 m) and -130 nT (60 m) were observed. This profile had mineral rocks with the highest and lowest magnetic responses. Profiles 3 and 4 (Fig 4b) indicated magnetic intensities (-150 to 260 nT) to a profile distance of 125 m. Profile 3 revealed high magnetic intensities of about 180 nT at profile lengths 30-35 and 50-55 m, and low magnetic intensities of about -130 and -150 nT at profile lengths 5-10 and 115 m respectively. Profile 4 indicated high magnetic intensities of about 260 and 280 nT at distances 40 and 80-85 m respectively. Low magnetic intensities of approximately 40 and 90 nT were revealed at profile length 110-115 and 15-20 m respectively. No negative response was observed in Profile 4 which indicated that materials with high magnetic intensities were embedded in the subsurface.

Profiles 5 and 6 (Fig 4c) had magnetic responses ranging between -140 and 150 nT to a profile length of 105 m. Profile 5 revealed high magnetic responses of about 90 and 120 nT at profile distances 40-45 and 105 m respectively. At profile lengths 10-15 and 25-30 m, low magnetic responses of approximately -40 and -110 were observed. Profile 6 shows high magnetic response of about 150 nT at profile lengths 5, 10-15, 25-30 and 35-40 m. Also, low magnetic response of about -140 was observed at profile lengths 70-75 m. Profiles 7 and 8 (Fig. 4d) revealed magnetic intensities ranging from -150 to 270 nT to a profile length of about 130 m. Profile 7 had high magnetic responses of about 150 and 180 nT at profile lengths 45 and 15 m respectively, and low magnetic intensities of about -125 and -150 nT at profile distances 75 and 60-65 m respectively. Profile 8 had high approximated magnetic responses of 150 and 270 nT at profile lengths 45-50 and 120 m respectively. Relatively low magnetic responses of about -70 and -110 nT were observed at profile lengths 65-70 and 55-60 m respectively.

The variations in the magnetic distributions were revealed in the profiles, and both the positive and negative residual magnetic fields were observed with more pronounced positive magnetic responses. Summarily, this study revealed high magnetic distributions (susceptibilities) in profiles 4 and 8, relatively low magnetic susceptibilities in profiles 5 and 6, and average magnetic susceptibilities in profiles 1, 2, 3 and 7.

4.2. Contour mapping

The residual magnetic anomalies were presented in scaled 2D and 3D contour sections (Figs 5-8) with the highest magnetic field intensity of 300 nT; this is relatively high compared to the spatial distribution of the magnetic survey.

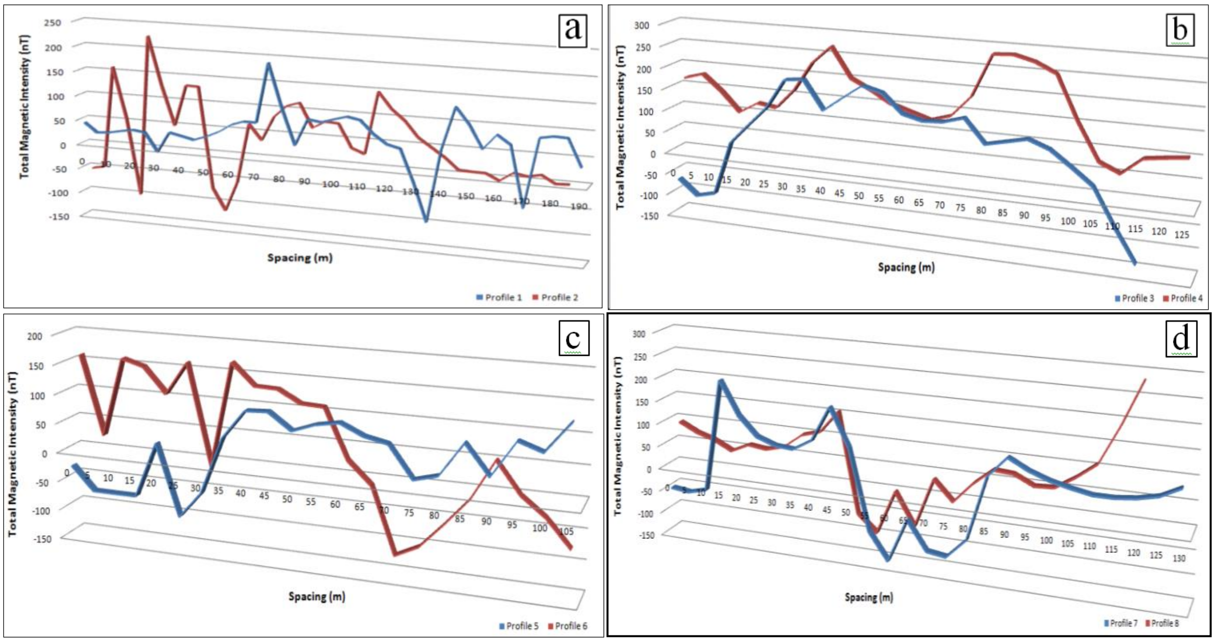

Fig 4. Profiles 1 and 2 (a), Profiles 3 and 4 (b), Profiles 5 and 6 (c) and Profiles 7 and 8 (d)

These sections were grid-based and visualized acute variations in the subsurface magnetic field intensities, indicating varied lithology and basement topography across the profiles. Moreover, on the contour maps, these variations can be classified into distinctive zones based on the magnetic field intensity variations of the sections which are possibly related to structural variations based on the geologic investigations. The magnetic intensities in the contour maps across the study area revealed highest magnetic susceptibilities ranging from 280-300 nT in Fig 6 (profiles 3 and 4) and Fig 8 (profiles 7 and 8); 180-200 nT in Fig 5 (profiles 1 and 2); and 140-150 nT in Fig 5 (profiles 1 and 2). These zones of high magnetic responses (140-300 nT) possibly harbored rocks such as Tantalite, Columbite and Tourmaline. The contour sections revealed that the zones with average magnetic susceptibilities (0-150 nT) were pronounced on the contour maps, and as such indicated that the study area is on quartz or pegmatite vein which possibly harbored mineral deposits such as Beryl, Quartz, Feldspar and Mica in both disseminated and massive quantities. Regions with low (0 to -150 nT) susceptibilities were also observed on the contour plots, and they possibly harbored mineral rocks such as Granite and Sandstone in high qualities. These results were actually in agreement with results obtained in the profiling (Fig 4).

The contour lines were widely spaced on the maps indicating that the depths to magnetic basements were relatively large. Also, closely spaced and linear sub-parallel oriented sections were observed across the profiles, and this suggested shallow magnetic anomalies which could also indicate faults or fractured zones. The contour maps generally revealed spikes which indicated massive presence of magnetic rocks in the subsurface. Also, the results obtained in this study were in agreement with some of the previous studies on pegmatite and quartz veins (Ajayi and Ogedengbe 2003; Okunlola et al. 2009; Ojo et al. 2014).

4.3 Peter's Half Slope Method

This technique estimated depth to basement analysis of mineral rocks in the study area using the results presented in Fig 4. Table 1 showed that the depths to magnetic sources for very thin, average and very thick bodies ranged from 3.48-6.40, 2.88-4.81 and 2.31-3.85 m respectively for profile 1; 5.05-12.63, 3.79-9.47 and 5.31-8.89 m respectively for profile 2; 7.84-14.80, 5.88-11.11 and 4.71-8.89 m respectively for profile 3; 12.03-15.74, 9.03-11.81 and 7.22-9.45 m respectively for profile 4; 4.36-8.82, 3.27-6.61 and 2.63-5.29 m respectively for profile 5; 4.54-12.12, 3.41-9.09 and 2.73-7.27 m respectively for profile 6; 3.48-8.71, 2.61-6.53 and 2.09-5.23 m respectively for profile 7; and 4.36-17.42, 3.27-13.06, 2.62-10.45 m respectively for profile 8. In general, depth estimates for the mineral rocks having very thin, average and very thick magnetic bodies ranged from 3.48-17.42, 2.61-13.06 and 2.09-10.45 m respectively. This indicated that the thin bodies were at deeper depths followed by the average bodies, and then the thick bodies.

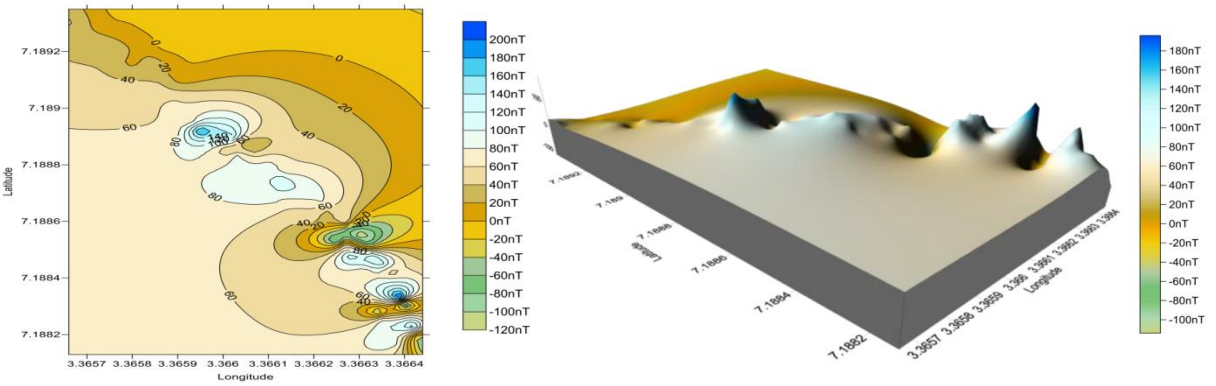

Fig 5. 2D and 3D Magnetic Response of Profiles 1 and 2

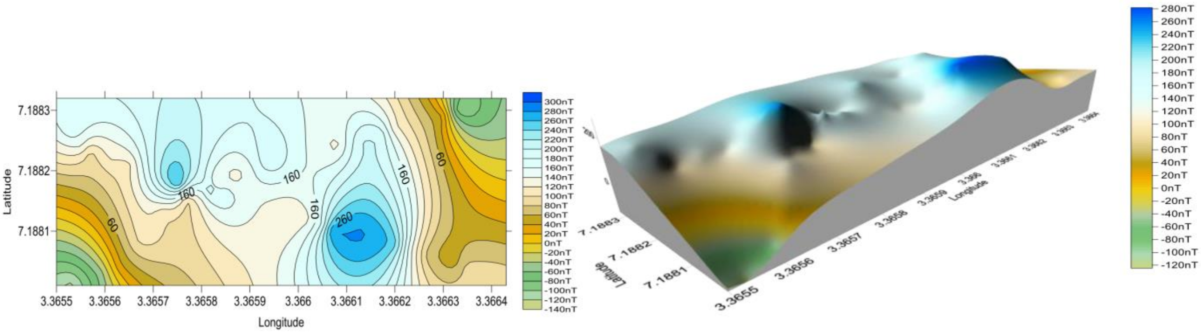

Fig 6. 2D and 3D Magnetic Response of Profiles 3 and 4

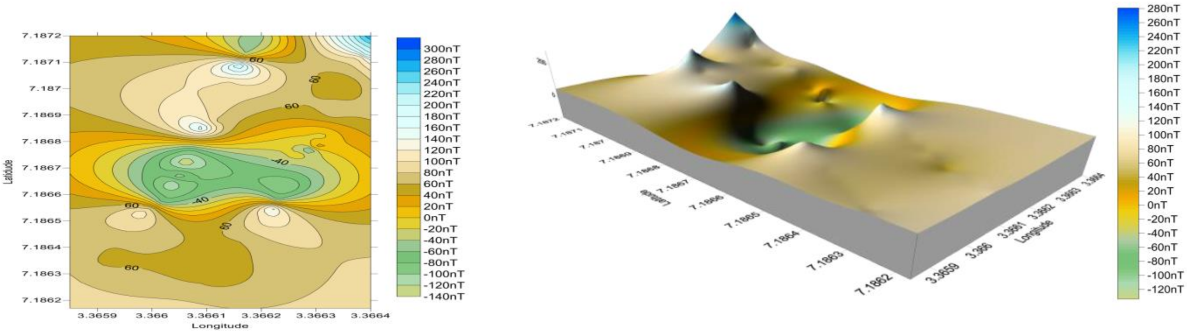

Fig 7. 2D and 3D Magnetic Response of Profiles 5 and 6

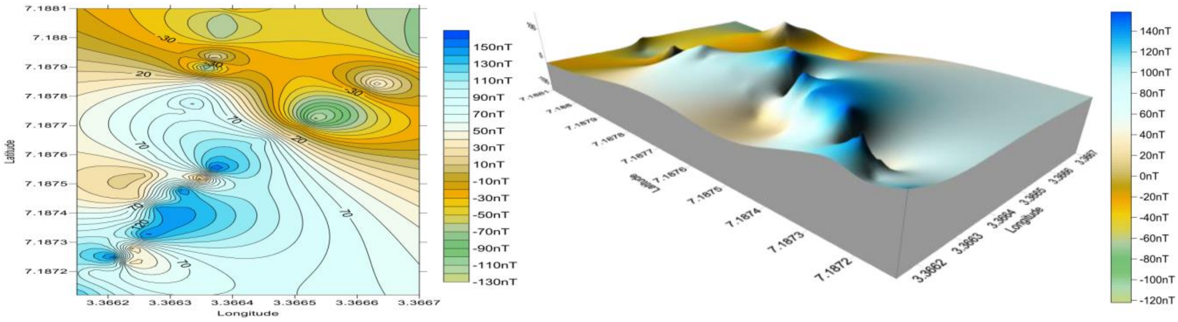

Fig 8. 2D and 3D Magnetic Response of Profiles 7 and 8

Table 1. Summary of depth estimates from the ground magnetic data

Profiles	Very Thin Body (m)	Average Thickness (m)	Very Thick Body (m)	Mean±SD (m)
1	6.40±0.80	4.81±0.12	3.85±0.68	5.02±0.53
	3.84±0.48	2.88±0.08	2.31±0.40	3.01±0.32
	5.13±0.64	3.84±0.10	3.08±0.54	4.02±0.43
2	5.05±0.63	3.79±0.10	3.03±0.54	3.96±0.42
	8.84±0.10	6.63±0.17	5.31±0.94	6.93±0.74
	12.63±1.58	9.47±0.24	7.58±1.33	9.89±1.05
3	14.80±1.85	11.11±0.28	8.89±1.56	11.60±1.23
	8.71±1.09	6.53±0.17	5.23±0.92	6.82±0.73
	7.84±0.98	5.88±0.15	4.71±0.83	6.14±0.65
4	12.03±1.50	9.03±0.23	7.22±1.28	9.43±1.00
	15.74±1.97	11.81±0.30	9.45±1.66	12.33±1.31
5	4.36±0.54	3.27±0.087	2.62±0.46	3.42±0.36
	5.88±0.73	4.41±0.12	3.53±0.62	4.61±0.49
	8.82±1.10	6.61±0.17	5.29±0.99	6.91±0.75
6	4.54±0.57	3.41±0.09	2.73±0.48	3.56±0.38
	12.12±1.52	9.09±0.23	7.27±1.28	9.49±1.01
	8.33±1.04	6.25±0.16	5.00±0.88	6.53±0.69
7	5.23±0.66	3.92±0.10	3.14±0.55	4.09±0.43
	8.71±1.09	6.53±0.17	5.23±0.92	6.82±0.73
	3.48±0.43	2.61±0.07	2.09±0.37	2.73±0.29
8	4.36±0.54	3.27±0.87	2.62±0.46	3.42±0.62
	9.58±1.20	7.19±0.18	5.75±1.02	7.51±0.80
	17.42±2.11	13.06±0.33	10.45±1.84	13.64±1.43
Mean±SD	10.24±1.05	6.32±0.20	5.06±0.89	6.60±0.71

*SD- Standard Deviation

This is contrary to the observation of Ojo et al. (2014) that very thin bodies were observed at shallow depths and thick bodies were estimated to be at deeper depths. This study has revealed that thin and average bodies can be found at any depth. Massive outcrops of rocks were noticed on the study area during the field survey, and this could have been responsible for the thick mineral bodies estimated to be at shallow depths.

The shapes of these buried mineral rocks were not specified by this method, it assumes that weathering and some other factors could leads to the deformation of these rocks over time, but give the possible geometry of the buried mineral rocks. Peters (1949) proposed that the shallower the depth, the thicker the body of the mineral rocks and the higher the magnetic anomaly susceptibility. Also, he explains that the deeper the depth, the thinner the magnetic body and the lower the magnetic anomaly susceptibility. The results of this study had confirmed the above proposal.

5. Conclusion

The magnetic signatures obtained from this study showed varying magnetic amplitudes with minimum susceptibility of about -150 nT and maximum susceptibility of approximately 300 nT. The study area is on a typical basement complex of southwestern Nigeria and located on a quartz or pegmatite veins which were known to harbor some economical viable mineral rocks. The magnetic susceptibilities measured suggested mineral rocks such as Beryl, Graphite, Sandstone, Quartz, Tantalite and Mica to be concealed in the study area. The depths of magnetic rocks having very thin bodies were observed between depths 3.48-17.42 m; intermediate bodies were found at depths ranging from 2.61-13.06; and very thick magnetic bodies were at depths range of 2.09-10.45 m. The thick bodies were at the shallow depths, while thin materials were logged at deeper depths. The average depths of the buried mineral rocks ranged between 2.09 and 17.42 m.

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